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## RESIDUAL LACTATION ACINI IN THE FEMALE BREAST

THEIR RELATION TO CHRONIC CYSTIC MASTITIS AND  
MALIGNANT DISEASE

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PHILADELPHIA

### THE EVOLUTION AND INVOLUTION OF THE HUMAN BREAST

In the embryo of the lower animal, and in the human embryo of 8 mm., or less, a delicate line extends from the axillary to the inguinal region along the junction of the abdominal wall and the membrana reunens. It is known as the milk line and consists of an epidermal thickening which later breaks up into ten or twelve nodal points, the rudiments of the future mammary glands.

In different animals a varying number of these glands persist and undergo further development while the remainder disappear, so that, with the completion of development, each animal is provided with the number of mammary glands normal to its kind, and in positions in conformity to its type. H. Schmidt has shown that human embryos are provided with a somewhat variable number of these rudiments, although normally only two survive, situated on the thorax in the pectoral region.

In embryos of from 14 to 15 mm. the rudiments are composed of circular aggregations of epidermal cells dipping downward into the derm. Later each becomes divided into a number of segments, and the central cells, becoming cornified, are cast off. At that time the future mammary gland appears as a depression on the skin. During the next few months the cellular segments elongate and become more or less cylindric, so that there is considerable resemblance between the appearance of the mammary rudiment and that of a sudoriparous gland. This has led some to believe that the mammary glands are enlarged and modified sweat glands, but the definite manner in which their rudiments are outlined seems sufficient to show that they are special organs. At this time the epithelial cylinders are solid, and so they remain, penetrating more deeply and more widely as the fetus grows.

Immediately after birth, in both sexes, the central cells of the cylinders disappear by vacuolation, and they become hollow and almost immediately filled and later distended by a copious exudation of fluid in which more or less fat appears, either as free droplets, or as droplets enclosed in cells similar to, if not identical with, the colostrum cells of the adult breast before lactation.

This is the so-called "witch's milk." At the time it appears there are no acini, such as appear during lactation in the adult breast. The secretion seems to exude from the ducts, lining which are cells which may contain fat droplets. In the course of a few weeks, the secretion and the enlargement of the gland that accompanies it gradually disappear, the fluid is absorbed, the tubules contract and return to much the same condition as before the change occurred, except that the lumina subsequently remain distinctly patent. The parenchyma of this still rudimentary mammary structure is distributed throughout a seemingly dense fibrillar tissue beneath the skin.

At a time, varying from the twelfth to the seventeenth year, usually between the thirteenth and fifteenth years, the glands in both sexes undergo further development, with very little increase in size in boys, but with great increase in size in girls. The division of the parenchyma into segments or lobes can be observed in the latter. There are from ten to twenty of these segments or lobes indistinctly separated from one another by intermediate bands of dense fibrillar tissue derived from the subjacent fascia, but so blended with the general connective tissue of the organ as to baffle demonstration by dissection.

The lobes, not definitely separable, have a pyramidal form, the bases at the periphery, the apexes at the center, where they converge at the future nipple. The parenchyma, at this time, consists of branching ducts, radiating from the nipple and distributed throughout the connective tissue.

At birth there is no nipple, instead there is a slight depression at the center of a circular area of modified skin, known as the areola. It is in immediate juxtaposition to this that the parenchyma of the future breast lies, and as it begins to grow at the time of puberty, the areola becomes elevated and projects in the form of a conical eminence. As the ducts continue to extend centripitally, and the stroma increases in quantity, the elevation embraces more and more tissue beyond the areola, the size increases, and a hemispheric shape is gradually assumed.

The hemisphere, however, remains surmounted by the small primitive cone so that the entire breast at this time is conical. In the darker colored races this is sometimes the final form of the mamma, but in

Caucasians there is a further change incidental to the appearance of muscular tissue about the nipple and backward traction of the fascia between the milk ducts. The result is flattening of the cone and the projection of the nipple. In the breasts of males the changes are much less striking, but there is increase of the parenchyma and development of a nipple.

Up to this time the breasts of both sexes are substantially alike, except that that of the female greatly exceeds that of the male in size and in the quantity of parenchyma. But what seems to be commonly overlooked is the fact that the breasts of both sexes frequently remain in this state of simplicity throughout the entire life of the individual unless some stimulus determines further development. On the other



Fig 1—Necropsy specimen from normal breast of R. N., aged 3 weeks, showing the dilatation of the ducts by the "witch's milk." There are no lobules and no acini. The magnification is too low to enable the cells lining the ducts to be recognized. (From the Philadelphia General Hospital.)

hand, in many cases, at this early period, and for no discoverable reason, the breasts seem to assume a much more highly complex development with the formation of the well known textbook lobule.

So far as known this structure never makes its appearance in the male breast, and in those cases in which the male breast has engaged in milk secretion, it seems to be through the activity of the cells of the ducts, as in the infantile activity resulting in "witch's milk."

According to the descriptions in the textbooks, the lobule is the characteristic element of the parenchyma of the mammary tissue. It

is of interest, therefore, to find that there are many cases in which it is completely or almost completely absent. In the breasts of seventeen girls and women known not to have borne children, and ranging in age from 12 to 70 years, no distinct lobules were found. This at first led to the assumption that the breasts of women that had never been pregnant were continually without definite and well formed lobules, and so gave the impression that it was possible from the examination of the breast alone to discover whether a woman had been pregnant or not. This seems to be a mistake. Through the kindness of Dr. Joseph C. Bloodgood, an opportunity was presented to supplement the study of the series of breasts secured at necropsy with breast tissue surrounding benign tumors of the breasts of unmarried girls and young women known not to have been pregnant, in many of which lobules were

TABLE 1.—CONDITION OF THE PARENCHYMA IN THE BREAST OF WOMEN KNOWN NOT TO HAVE HAD CHILDREN

Age in Years	Condition of Parenchyma
12	Ducts in small groups, no lobules
12	Rudimentary lobules, very small
14	Rudimentary lobules, very small
15	Rudimentary lobules, very small
17	A few well developed lobules (This girl had carcinoma of the other breast)
18	No lobules
21	Few well developed lobules of small size (The ovaries had been removed at 19)
26	No lobules
40	A few small rudimentary lobules
47	A few small rudimentary lobules
47	A good many large rudimentary lobules
51	Occasional small rudimentary lobules
53	No lobules
56	A few small rudimentary lobules
65	No lobules
65	No lobules
70	No lobules

present, some being well formed. The histologic structure of the virgin breast is therefore varied. For convenience of description it can be divided into parenchyma and stroma.

I. *The Parenchyma*.—In its most simple form the parenchyma consists of tubular structures that are easily recognized as ducts. In sections they may appear singly or may be collected in groups. To the latter it seems appropriate to apply the term *rudimentary lobule*. They differ from the developed, or textbook, lobule through the absence of distinct periductal tissue.

The size of the ducts is variable, some are small, with very inconsiderable lumina, others are large, with widely dilated lumina. They almost always have distinct lumina, primarily because of the infantile secretion already referred to, and because of subsequent periodic activity of a secretory character. It is well known that young women not infrequently experience slight tenderness of the breasts at the time of menstruation, and some of them are at that time able to discover a

slight amount of moisture in the breasts. Others observe swelling of the glands, and a few are able to express considerable watery secretion. Rare cases are on record in which with each recurring menstrual period a distinct milky secretion has occurred.

The ducts appearing in the sections are not always empty. They are likely to contain more or less jelly-like material that probably results from the action of the fixatives on the proteins in the secretion which they contained, and in it there may be some admixture of fatty molecules.

The rudimentary lobules may be numerous and large and may pass by imperceptible gradations into the atypical or textbook lobules which are characterized by the presence of abundant periductal tissue.



Fig. 2—Necropsy specimen from normal breast of T. B., man aged 38. The stroma of the breast corresponds to the perilobular stroma of the virgin female breast. In it only a few fat cells can be detected. The glandular parenchyma is represented solely by ducts, and the structure is identical with that found in the breast of the young virgin. (From the Philadelphia General Hospital.)

The structure of the ducts is simple, consisting of a basement membrane, not always easy to define on account of its thinness, and a single layer of cells. The appearance of these will vary according to the region from which the section is removed. If deep in the breast, the ducts are always lined with epithelium of cuboidal type, if near the nipple, by epithelium which becomes higher and more nearly columnar as the dilatations—milk sinuses—below the nipple are approached.



If a milk duct could be followed from its ending in the nipple to its beginning deep in the parenchyma, it would be found that the squamous epithelium of the outer skin dips a short distance into it, then suddenly changes to columnar epithelium, which continues a considerable distance, until the duct has divided several times, after which it gradually changes to cuboidal epithelium. As the fragments of tissue collected for the prosecution of this research were not intended for the determination of the structure of the ducts, they were taken from deeper portions than were appropriate, and observations on this point were merely incidental. Rugosity of the ducts was very common, as

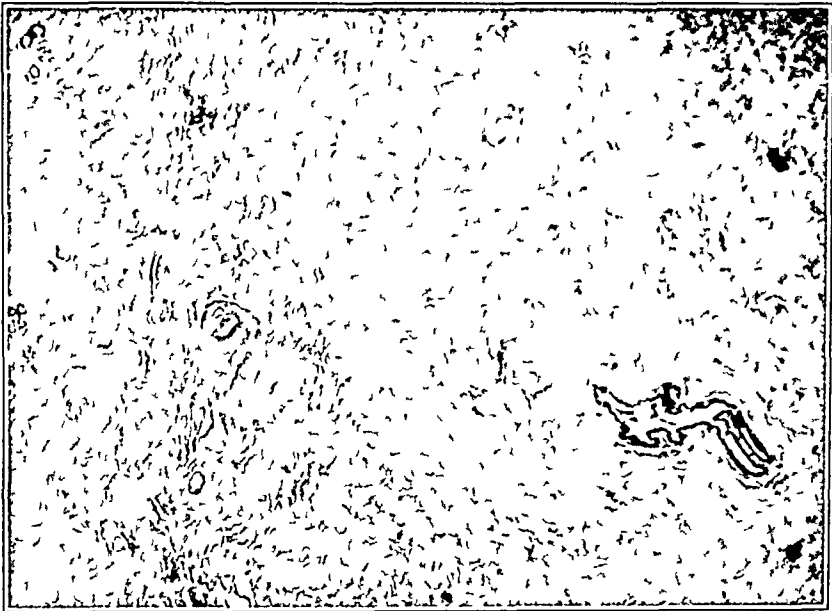


Fig 3—Necropsy specimen from normal breast of M W, colored girl, aged 12 years. The stroma is almost entirely composed of purely fibrillar, perilobular connective tissue. Extending from the lower edge of the section toward the blood vessel, to the left of the center, there is some interlobular connective tissue. The parenchyma consists solely of ducts and minute rudimentary lobules, one of the former being conspicuous to the right of the center, one of the latter is in the upper left corner. There was no fat in this breast, though it was quite shapely and well developed. (From the Philadelphia General Hospital.)

might be predicted from the frequency with which they are subject to distention and contraction with the variations of secretory activity.

From the rudimentary lobules composed of congeries of small ducts, without the number of tubular structures and the connecting periductal tissue characteristic of the classical lobule, one passed, in the series of cases studied, imperceptibly into the latter. That is, there were cases with no parenchymatous structures other than ducts, cases with rudi-

mentary lobules, cases with rudimentary lobules of large size, cases with large and small rudimentary lobules and small classical lobules, and cases with many large classical lobules

So far as could be determined, there was no difference between the lobules in these virgin breasts and those in the mammae of parous women so that the presence or absence of lobules does not form a means of determining the virgin state of the breast. The consideration of further particulars of the histology of the lobules themselves will be postponed until the history of the mammary lobule is described.

But here it must be pointed out that the development of the breast at the time of puberty, as well as later, and its extreme development at

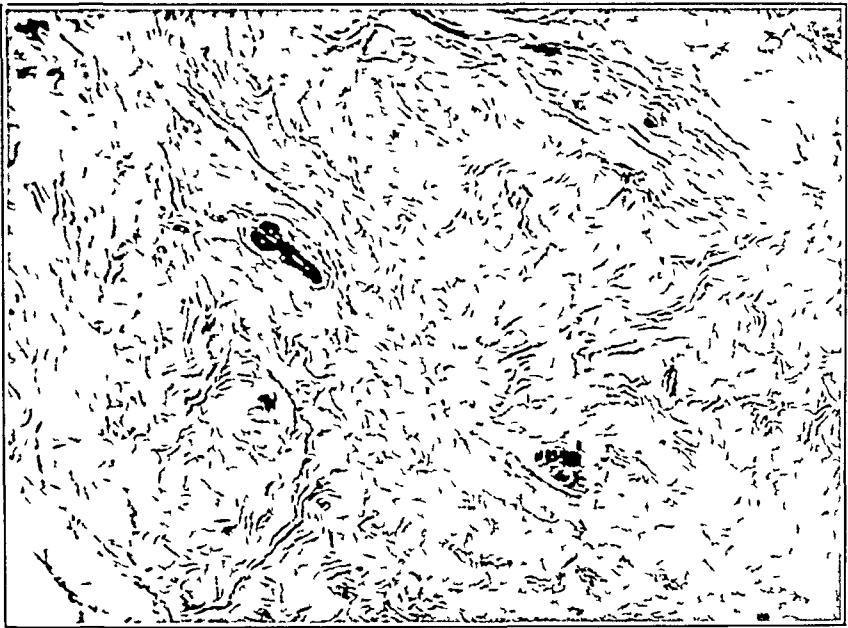


Fig 4—Necropsy specimen from normal breast of L. D., white girl, aged 12 years, showing rudimentary lobules in the virgin breast, as well as the perilobular connective tissue above them and near the two opposite diagonal corners, the interlobular connective tissue which contains a few fatty deposits. The perilobular tissue is purely fibrillar in character. (From the Philadelphia General Hospital.)

the time that it is preparing for lactation, can only be accounted for as depending on certain stimuli. If these are efficient, the breast develops irrespective of everything else.

Of the nature of these stimulants nothing need be said here, the subject is physiologic, and is sufficient to fill a good sized paper in itself, but with respect to the response to stimuli, it is necessary to point out certain things at this point. In certain cases the stimulus may be excessive and come early, so that the growth of the breast at puberty does not cease at the development to the usual size, but continues to

an enormous size—puberty hypertrophy. Again, there are numerous cases in which the puberty hypertrophy is followed by the attainment of the normal size, but the occurrence of pregnancy is followed by the excessive development—pregnancy hypertrophy. Then there are still other cases in which for no discoverable reason the breast develops excessively, sometimes uniformly and on both sides, sometimes only on one side—nondescript hypertrophy. But what is of more interest now is the fact that the growth may be limited and localized, and therefore not referable to endocrine substances reaching it through the blood but apparently dependent on local conditions resident in the breast itself. Such seemed to be the case in numerous of the sections shown by Bloodgood taken from tissue surrounding benign encapsulated

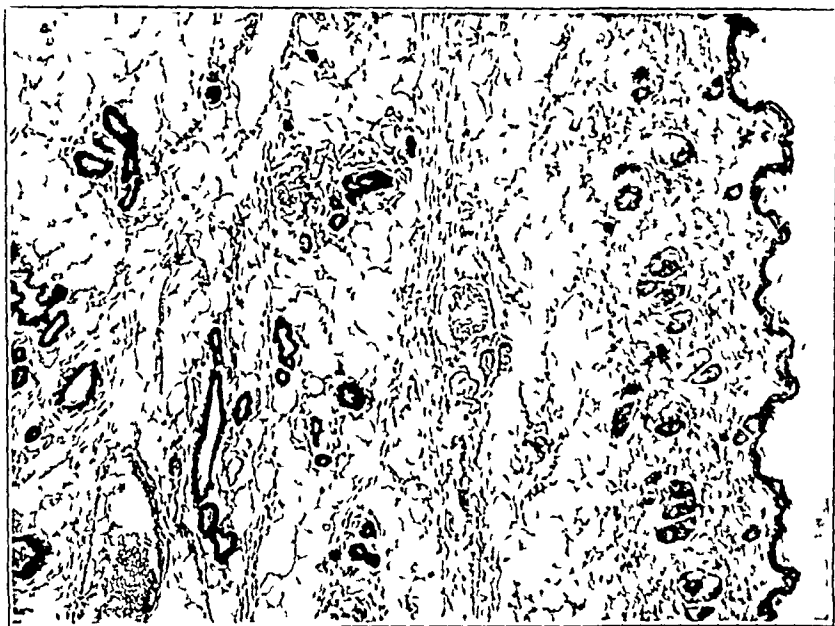


Fig 5—Mammary gland of virgin rat. The animal was three-fourths grown and in fine breeding condition, but it had been kept from the males. There are no lobules, the parenchyma of the gland is composed solely of ducts.

tumors in young women and girls. The appearance of the mammary tissue differed according to the proximity of the tumor. Away from it, the breast had a composition like that of the virgin breast already described, but as the tumor was approached, the lobules became larger and larger, until many of them appeared exactly like those of a breast that had recently been lactating. Unfortunately, there were no sections available from other parts of the breasts of these subjects from which it could be determined whether this development of the lobules was as local as it seemed, or was to be found in parts of the breast remote from the tumors.

From several of the sections it was difficult to come to any other conclusion than that the general structure of the breast was composed of a parenchyma made up of rudimentary lobules, which increased in size and development as the neighborhood of the tumor was reached

But regardless of such local conditions as may play a part in their development, and of unusual stimuli governing their occasional maturation, it is pregnancy that is the great determinant of lobular growth and development in the breast, and to it I shall return later

II *The Stroma*—To the palpating fingers the normal breast is soft but lacking in uniformity. It is hard to describe the exact sensation, but it is commonly said to be "corded," the source of the inequality being referred by some writers to the presence of vessels and milk

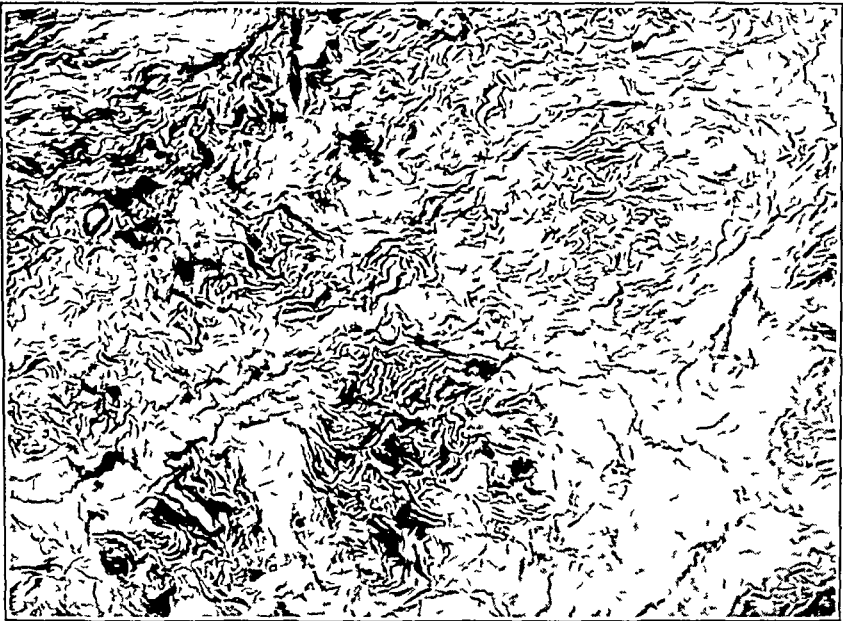


Fig 6—Necropsy specimen from normal breast of J S, white woman, aged 22, showing the mucinoid stroma, as well as the fibrillar structure of the juvenile mammary gland. There is no fat in the perilobular tissue shown

ducts. It is obvious that this is a mistake. Vessels are few and deeply seated. Milk ducts are also centrally and deeply seated, and their delicate structure makes it impossible to feel them. The real source of the inequality is the structure of the stroma which is peculiar both in quality and in distribution. It is primarily and fundamentally fibrillar, and may be divided as follows

1 *Interlobar Connective Tissue*. This seems to be derived from the pectoral fascia, and extends upward, dividing the whole substance of the gland into the lobes already described. In it a varying quantity of adipose tissue is present. The general fatness or leanness of the

body seems to have little to do with the quantity of adipose tissue in the breast, however. The breasts of some lean women contain a great deal of fat and are large in consequence, those of some fat women contain very little fat and are small in consequence. In the breasts of one very fat woman, in our necropsy series, there was scarcely any adipose tissue.

2 The Interlobular Connective Tissue. This extends throughout the entire mammary tissue between its lobules, or in the case of virgins between the potential lobules represented by the ducts and rudimentary lobules. In it occasional fat vacuoles may be found at any age, but fat regularly begins to appear as age increases. This is not a fixed rule but it applies well in averaging the cases, with respect to both virgins and parous women as will be evident by comparing the accompanying tables showing the conditions of the stroma in parous and nonparous women.

TABLE 2—MICROSCOPIC STRUCTURE OF THE STROMA OF THE BREAST IN PAROUS AND IN NONPAROUS WOMEN

	Number of Cases Studied	Average Age of Women Years
I Nonparous women	17	36.7
Stroma fibrillar only	6	24
Stroma fibrillar and mucinoid	4	42
Stroma fibrillar, mucinoid and fatty	3	50
Stroma fibrillar and fatty	4	39
II Parous women	124	46.2
Stroma fibrillar only	11	32.7
Stroma fibrillar and mucinoid	62	42.6
Stroma fibrillar, mucinoid and fatty	48	52
Stroma fibrillar and fatty mostly fatty	3	58
Among the nonparous women the stroma was mucinoid in		41.17 per cent
Among the parous women the stroma was mucinoid in		88.7 per cent
Among the nonparous women the stroma was fatty in		41.17 per cent
Among the parous women the stroma was fatty in		41.12 per cent

It is thus seen that though there may be considerable adipose tissue in the interlobar tissue of the breast in youth, not much is to be expected to appear in the interlobular tissue until after the menopause. This may have an important bearing when it is remembered that in excising fragments of breast tissue for microscopic examination, the interlobar fat which is immediately visible is usually avoided in favor of the white tissue of the breast itself, which consists in large measure of the interlobular tissue.

Since the adipose tissue is so unequal in its presence and distribution, it cannot be to it that the breast owes its softness, the organ is soft, though firm in youth when very little fat is contained in its substance, soft and flabby in old women, when much fat is present. The fibrillar breasts of youth are protuberant, the fatty breasts of age, pendulous.

The interlobular distribution of the adipose tissue in the breast of young women and its interlobar and interlobular distribution in the breasts of older women may largely explain the inequality of the mammary tissue to which the 'corded' sensation is due. The softness of the adipose tissue alternates with the firmer fibrillar tissue. But there is another factor of great importance in accounting for the soft consistency of the mammary tissue, that is, the mucinoid condition so common in its connective tissue. As has been shown in the tabulation, 41 per cent of the breasts of nonparous women and 88 per cent of those of parous women showed this condition in the fragments of tissue examined. It is quite probable that if greater areas of the breast



Fig 7—Necropsy specimen from normal breast of W S, white woman, aged 81, showing calcification of the middle coat of a branch of the mammary artery (From the Philadelphia General Hospital)

tissue had been subjected to examination, a greater number of breasts would have shown it. Here is introduced a source of error that generally pervades the research. The breast is such a large organ that it is quite impossible to subject every part of it to microscopic examination, a supposedly representative sample is selected, and with what is seen in it one must be content, especially if a large number of cases are to be studied.

The change that is called mucinoid seems to result from some kind of softening of the collagen fibers of the connective tissue, which seem to lose distinctness and coalesce in a homogeneous mass through which capillary and other blood vessels and ducts are distributed and in

which lobules may lie embedded. At first it was supposed to be truly mucinoid, and like the gelatinous change so frequently seen in the tissue of tumors. But it fails to give the chemical reactions of the mucins, and it has not been possible to determine its true nature. It was at first looked upon as pathologic and possibly referable to disturbed conditions of the circulation, probably depending upon disease of the blood vessels. As will later be shown, disease of the blood vessels is of not infrequent occurrence in the breast, but it is impossible that the condition under consideration, which occurs in 88 per cent of normal breasts and sets in after middle life with such regularity can be so caused. It is sometimes found as early as the eighteenth year, and occurs in both virgins and parous women.

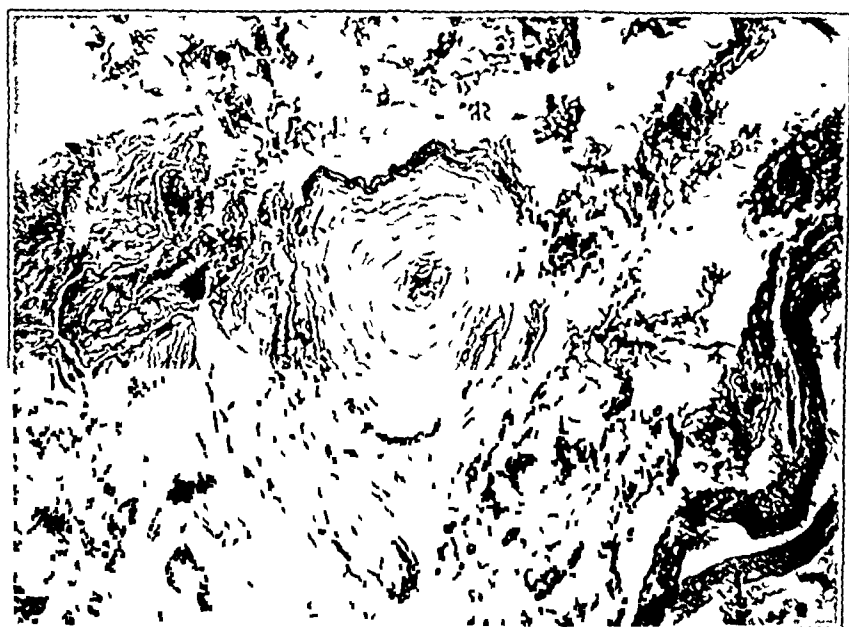


Fig. 8—Necropsy specimen from normal breast of M. C., white woman, aged 53, showing a corpuscle of Pacini. It lies as is usual, in the interlobular connective tissue, not far from the blood vessels. (From the Philadelphia General Hospital.)

It has, moreover, a somewhat regular distribution, occurring rather more frequently in the interlobular than in the perilobular tissue soon to be described. In some cases it occurs in the form of occasional fibers which, among those of ordinary appearance, show it through greater size and homogeneous appearance, sometimes whole strands of the fibers show it, sometimes great areas of tissue are so altered as to appear structureless and colorless or reddish from the eosin counter-stain.

3. The Perilobular Connective Tissue. This immediately surrounds the ducts and lobules in a more or less concentric fashion and seems

to be the last to undergo either the fatty or the mucinoid change. In many cases it is a distinct and easily recognizable tissue, but in others it is difficult to separate it from the interlobular tissue. It must be distinguished from the periductal tissue, which is intralobular, and will be considered with the parenchyma. Its distinctness is possibly due to the direction in which the section is cut. Should this be a fact it will serve to explain why in certain sections it is so distinct as to cause the section to be divided into many distinct entities, as the liver is divided into lobules in the center of each of which there appears a duct—a small lobule. This perilobular connective tissue is destined to disappear in part or altogether when lactation hypertrophy occurs, and might, therefore, be expected to be of delicate structure and



Fig 9—Necropsy specimen from normal breast of M. M., white woman, aged 25, eighth month of pregnancy. The lobules have already attained a large size and many of the acini are dilated by beginning secretion which also fills the ducts. (From the Philadelphia General Hospital.)

mucinoid character. That is, however, not the case, it usually appears dense. In all of these connective tissues there are collagen, fibroglia and elastic fibers, varying somewhat in quantity and in distribution according to the activities and metamorphoses through which the breast has passed in the course of a long life, including numerous pregnancies and lactations.

The stroma of the breast also contains vessels and nerves. Their presence depends upon the part of the organ from which the fragment for examination has been excised.



1 Arteries These are usually small or of medium size, and are contracted. Occasionally, they show calcification of the middle coat, when they seem to lose their normal resisting power and undergo more or less dilatation. As usual, the calcification seems to be preceded by hyaline degeneration. No calcified vessels were found before the menopause. They were discovered at the ages given in Table 3.

2 Veins The only change observed in the veins was dilatation, which seemed to be of frequent occurrence.

3 Nerves Nerves were present in a number of the sections. Most of them were found unexpectedly, they were sometimes single and sometimes in groups. No pathologic alteration was noted in any of them.

The occurrence of the corpuscles of Vater, or pacinian corpuscles, was noted by Kolliker many years ago, but it is unusual to see them in sections made for pathologic study. It is probable that misinterpretations have arisen from their peculiar appearance and rarity. One

TABLE 3—AGES AT WHICH CALCIFIED VESSELS WERE FOUND

Age in Years	Race	No. of Children	
47	Colored	2	
51	White	5	
55	Colored		
62	White	7	
66	White	2	
68	White	2	
70	White	1	
75	White		Hyaline degeneration
78	White		
81	White	1	
84	White	2	

was shown to a competent microscopist who after examining it critically suggested that it was a peculiar form of laminated thrombus. In the 150 cases upon which this research is based they were found eight times. Being normal and permanent structures, in all probability connected with the sensory system of nerves, the age at which they occur is of no consequence, varying from 16 days to 78 years. Like the nerves themselves the pacinian corpuscles are found in the interlobular connective tissue, near the larger blood vessels. They are large and striking objects, and not to be mistaken for anything else, by those familiar with them.

Except there be such obvious pathologic disturbances as suppuration, round cell infiltration, calcification or hemorrhage, the condition of the stroma of the breast seems to be a very insecure guide to the determination of the normality or abnormality of the organ, as it varies greatly according to the age, the sexual activity, and the individuality of the patient. Most of the breasts that come to microscopic study have been removed surgically, and taken from middle aged

women who have borne children. They present an appearance characteristic of that time of life and activity, with which all surgical pathologists become familiar. A breast from a virgin, many years younger presents a very different appearance. In the former, there is likely to be a considerable admixture of fat, with corresponding diminution of fibrillar tissue, in the latter, there may be no adipose tissue, and much fibrillar tissue, a condition that is likely to be interpreted immediately to mean a pathologic condition of fibrosis, especially when the large amount of parenchyma in the former is compared with the very small amount in the latter, and the absence of lobules is taken



Fig 10—Necropsy specimen from normal breast of E. R., white woman, aged 23, who died of puerperal sepsis two days after the birth of her third child. There is great inequality in the size of the acini, some of which are entirely empty and contracted, others widely dilated, as in full lactation hypertrophy (From the Philadelphia General Hospital.)

into consideration. It is suspected that the growth of the fibrillar tissue has resulted in the extinction of the lobules, when, as a matter of fact, there never were any there, and the presence of the fibrillar tissue is normal.

#### THE EVOLUTION OF THE BREAST FOR THE PERFORMANCE OF ITS FUNCTION—LACTATION

The great modifier of the mammary structure is pregnancy. It is with the occurrence of this state that the lobules invariably appear;

and after the menopause, when it is no longer possible, that they tend to disappear. Most of the subsequent history of the mammary gland has, therefore, to do with its lobules.

*The History of the Mammary Lobule*—The starting point of the investigation should be the changes that occur in the breast of the primipara, and lead to the appearance of the lactation tissue. The rarity with which primiparous women die in the early months of pregnancy explains the first difficulty encountered—the inability to obtain the desired and necessary material. In our collection there were but two cases of very early pregnancy, but in each there had been prior pregnancies by which the conditions were so modified as to

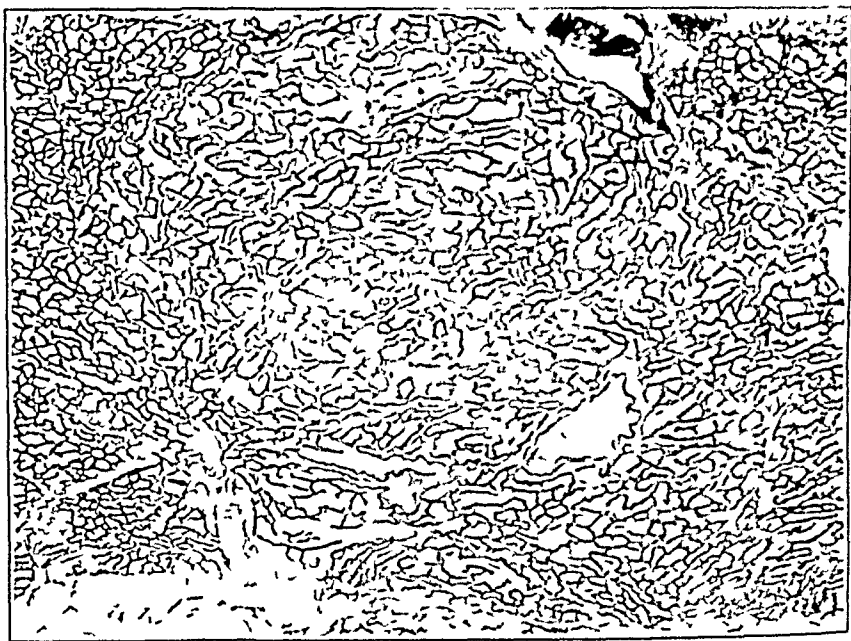


Fig. 11—Necropsy specimen from normal breast of M. M. White, aged 34, mother of six children, one of whom she was nursing at the time of her death. The breast shows full lactation hypertrophy under low magnification. The perilobular tissue has disappeared and the interlobular tissue is represented only by fibrous partitions that support the blood vessels. The acini, which are somewhat collapsed because the secretion escaped when the tissue was cut, are of irregular shape and into many of them slender projections extend like stumps of ruptured interlobular septums. Similar formations appear in the residual lactation acini. (From the Philadelphia General Hospital.)

make them valueless in answering the question of the early changes. In each the effects of the previous lactations were confused with those of the present one.

The observations, therefore, were begun with the study of the breast of a young primipara in the fifth month of pregnancy. At this time the increase of mammary parenchyma was astonishing, there

being a large number of lobules, varying in size from minuteness to a diameter great enough to fill an entire field under a low power magnification (Zeiss AA, ocular 4)

It is evident therefore, that the mammary hypertrophy does not progress uniformly, but is more rapid in certain portions than elsewhere. Presumably, a study of the structure of the smallest of the lobules gives the best clue to the inception of the process. From these sections, it was determined that the hypertrophy of the parenchyma begins through budding from the ducts. In not a few areas there were small ducts wrinkled and puckered, as though buds were

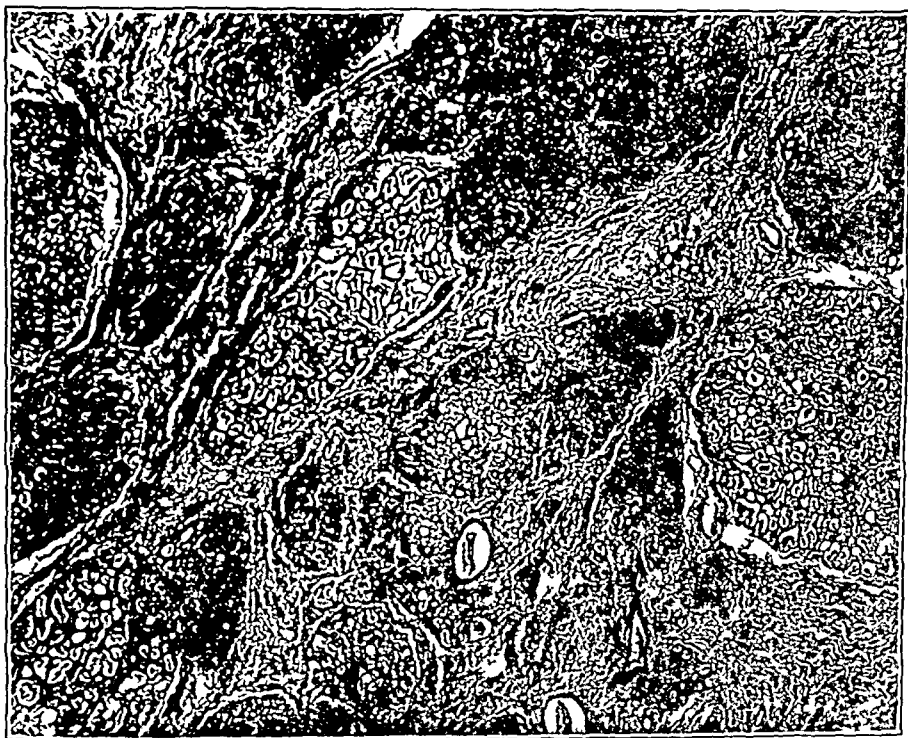


Fig 12—Necropsy specimen from normal breast of E. R., white woman, aged 23, delivered of a baby, Jan 23, 1921, died of streptococcic puerperal infection a few days later in the Philadelphia General Hospital. The breast is in a condition of full lactation hypertrophy but no active secretion has begun. The quantity in the acini is not greater than it is in the earlier months of pregnancy (From the Philadelphia General Hospital)

growing out from their walls. From these, other smaller puckers were sometimes discoverable, as though secondary buds were forming from the primary ones.

At these points, there was no discoverable basement membrane, (The basement membrane of the parenchyma of the mammary gland is always difficult to define except in lobules long inactive.) The epithelial buds seemed frequently to be solid and composed of masses

of cells without differentiation. Through early vacuolation and fatty secretion by the cells, the centrally situated cells disappear, leaving lumina in the new formation. In this manner the parenchyma developed, acinus being added to acinus, and groups of acini collecting about the ducts and ductules. The acini first formed usually showed more or less secretion, which appeared in the sections either as jelly-like cylinders, or as collections of jelly mixed with fatty globules of considerable size.

There was another element of the parenchyma that merits attention—the intralobular or periductal connective tissue. The budding of the parenchyma scarcely begins before the growing ducts and developing

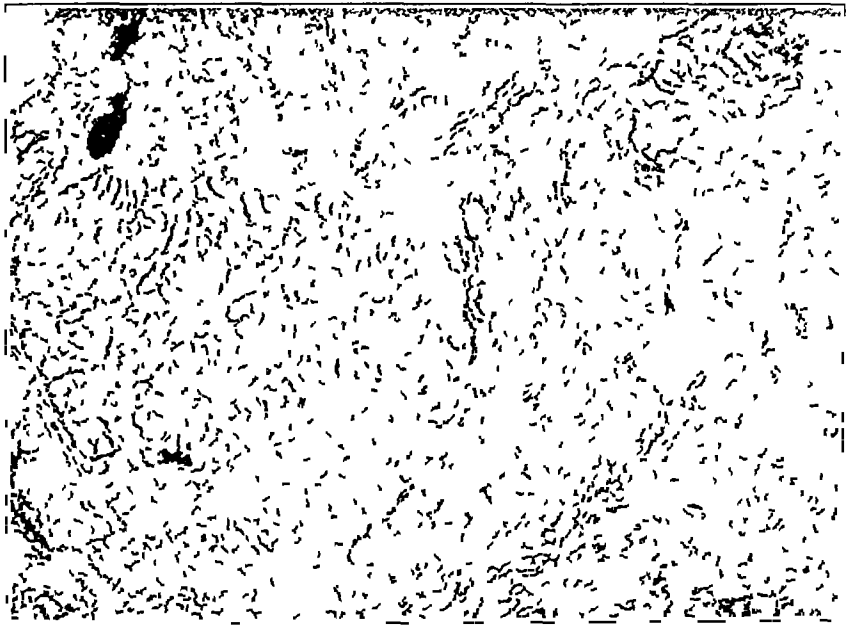


Fig. 13—Necropsy specimen from normal breast of C. P., aged 28, white woman, mother of four children, date of last lactation not known. The greater part of the illustration shows parenchyma in the earlier nuclear stage of involution. The large lobule on the left has delayed its involution and its acini retain the lactation appearance. Such elements may evolve into residual lactation acini. (From the Philadelphia General Hospital.)

lobules are surrounded by broad areas of peculiar pale connective tissue, sharply differentiated from the perilobular tissue, and suggesting by its looseness and pallor an edematous condition. It is into this loose soft tissue that the budding parenchyma extends at first. But soon it seems to reach a point when it is no longer necessary for it to be preceded by this new formation, and it grows more rapidly than its associated connective tissue which seems to be lost by distribution. In breasts of women in the seventh, eighth and ninth months of preg-

nancy, periductal tissue is scarcely to be seen, the entire enormous lobules being composed of closely approximated acini. The dense, or seemingly dense perilobular connective tissue is thrust aside in some manner, giving the impression that the growth of each lobule is like that of a benign tumor in which there is no peripheral infiltration, but only interstitial expansion. The perilobular tissue is not invaded and opened up by the acini, it is pushed aside and thinned more and more by the lobules, as they increase in size, until it is brought into juxtaposition with the interlobular tissue.

Secretion of fluid seems to begin almost as soon as the parenchyma begins to grow, but it is only after the fifth month of pregnancy that expression of fluid from the nipple is possible. The colostrum

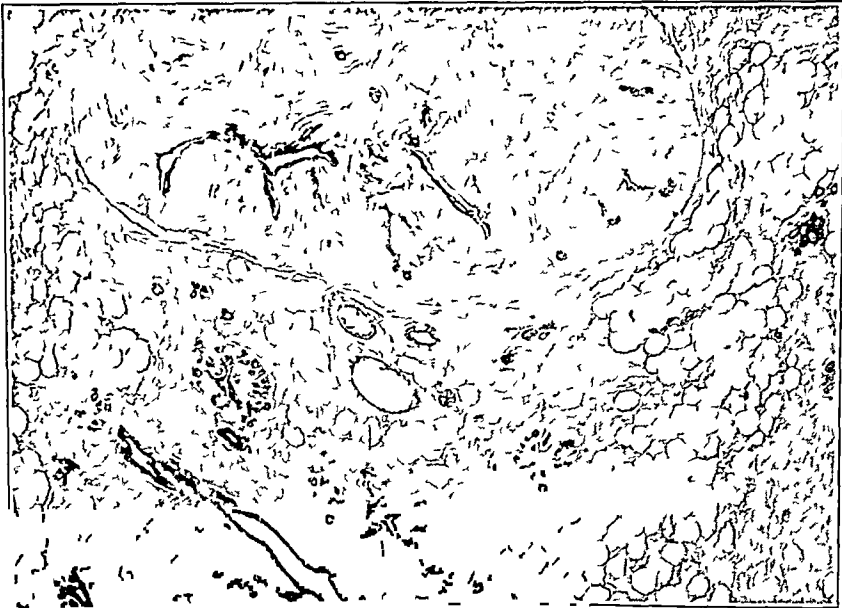


Fig. 14—Necropsy specimen from normal breast of S. S., white woman, aged 19, died one year after having borne her first baby. The breast shows rapid involution. In the upper part of the illustration there is a large lobule almost entirely composed of periductal tissue. Below are several circumscribed lobules more nearly corresponding to the textbook illustrations. There are also several small uncircumscribed lobules. (From the Philadelphia General Hospital.)

cells seem to be the central cells of the newly formed acini, vacuolated by fat, or filled with fatty molecules that escape from the future acini as they are in process of forming lumina. They are relatively few in cases in which the secretion is scanty, and the lumen formation of the acini delicate, and many when there is much secretion and the lumen formation considerable. Sometimes quantities of them collect in the larger ducts. It did not seem possible that they were, as some think, leukocytes distended with molecular fat.

At the end of pregnancy, the quantity of parenchyma in the mammary glands varies greatly in different cases. In general, when compared with the quantity found in the breast of full lactation, it is surprisingly small, and gives the impression that lactation with adequate nutrition of the child would be impossible. There must be increase during the first few days postpartum, greater than anything that has gone before, probably through the new stimulus resulting from the application of the child to the breast. With the "coming of the milk" all of the newly formed acini dilate widely to an extent that seems to cause the rupture of some of their walls, as many of the larger ones have portions of interacinar septums sticking out like stumps into their spaces. The dilatation causes the partitions between the acini to

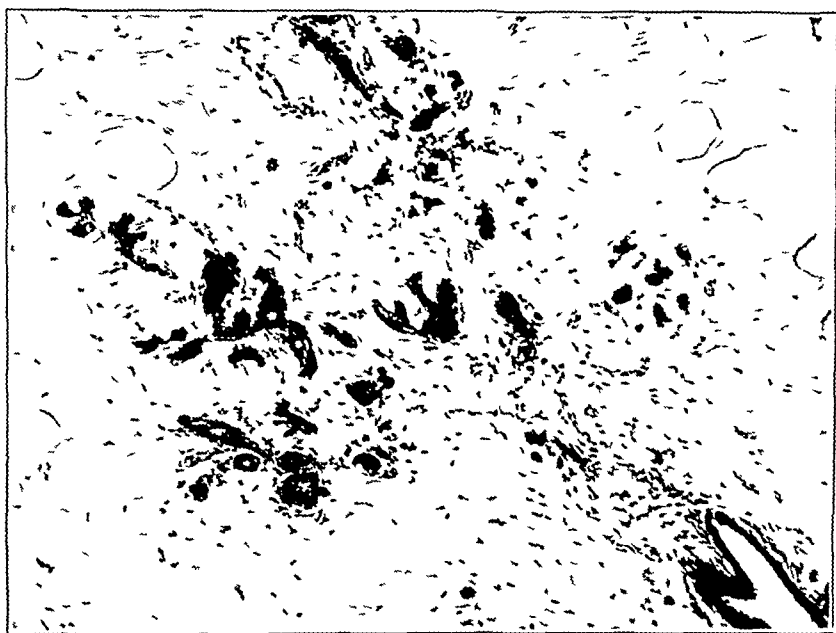


Fig 15—Necropsy specimen from normal breast of S. S., aged 19, white woman, showing an uncircumscribed and disrupted lobule following rapid involution. The patient had had a baby the year before she died. Fat cells can be seen in the interlobular tissue at the sides of the illustration. The periductal tissue can scarcely be recognized because of confused growth into the perilobular tissue (From the Philadelphia General Hospital.)

become thin and the cells to be flattened. The flattening of the cells, together with the presence of many globules of fat in them, makes it difficult to determine the exact structure of the interacinar walls, with respect to the presence or absence of both mammary and basket cells. They are probably both there, the latter being compressed and difficult to see.

In full lactation hypertrophy, the periductal tissue disappears from view, the perilobular connective tissue can no longer be found, the

adipose tissue is completely absorbed and the interlobular connective tissue remains only as narrow strands separating large groups of lobules. Upon more careful observation in appropriate cases the outline of the lobules by the perilobular tissue can be made out, and gives an impression analogous to that produced by the outlining of the lobules of the liver of rodents by the bands of periportal connective tissue.

Thus the breast attains its full glandular perfection, and is transformed into a parenchymatous structure composed of lobules of fairly uniform size, closely approximated, and made up of newly formed structures, the acini. In this state it remains as long as the mother continues to lactate. With the weaning of the baby, the parenchyma ceases to be of further use, it seems by nature to be superfluous, and nature at once begins the process of getting rid of it.

TABLE 4—SYNOPSIS OF THE MICROSCOPIC STUDIES OF SIXTY-EIGHT BREASTS OF WOMEN OF THE CHILD-BEARING AGE

	Groups *				
	I	II	III	IV	V
No lobules in the sections	15	0	0	0	3
Lobules, large and numerous	0	3	9	7	0
Lobules, large but few	0	1	0	1	0
Lobules, small	0	5	2	3	0
Lobules, vestigial—disappearing	0	5	11	3	0
Lobules well circumscribed	0	3	3	2	0
Lobules, not well circumscribed	0	5	7	4	0
Lobules uniform	0	1	1	1	0
Periductal tissue conspicuous	0	2	4	0	0
Periductal tissue not uniformly distributed in lobules	0	5	15	10	0
Periductal tissue hyaline	0	1	0	0	0
Residual lactation acini	0	2	2	1	0
Microcysts	0	1	2	1	0
Large ducts, numerous	0	2	3	0	0

\* Group I includes the breasts of women known not to have had children, microscopic confirmation; Group II, those of women known to have had children, microscopic confirmation; Group III, those of women known to have been married, microscopic evidences of lactation; Group IV, those of women in whose history there is no information as to matrimony or maternity, but whose breasts show microscopic evidences of lactation, and Group V, those of women with no history or microscopic evidence of lactation.

#### THE INVOLUTION OF THE BREAST AFTER LACTATION

It must, of course, be understood that the evolution of the parenchyma may miscarry anywhere along the line, and further development cease. Such a condition arises in cases of abortion, miscarriage, refusal on the part of the mother to nurse her child, the death of the infant at the time of birth, etc.

In these cases the breast ceases to evolve, but the occurrence of the pregnancy having been enough to initiate the formation of lobules, although incompletely developed, they at once begin the changes characteristic of involution.

The process of involution rarely proceeds uniformly and regularly, because all parts of the secreting breast are not uniformly active in secretion at the same time unless it is when the child is applied to



the breast and the maximum of secretory stimulation brought about. The examination of sections of breasts preparing for lactation and ceasing lactation will easily convince the observer of this, for in both cases there will be found in the same lobules of the mammary parenchyma a number of acini that appear of small size and are empty, and others that are distended with some kind of secretion. It seems as though the retention of the secretory function by some of the acini, and their distention by the products of that secretion interfere with the uniformity of involution. The varying degrees of interference arising from the varying conditions obtaining in different breasts cause remarkable differences in their microscopic appearance. In the same

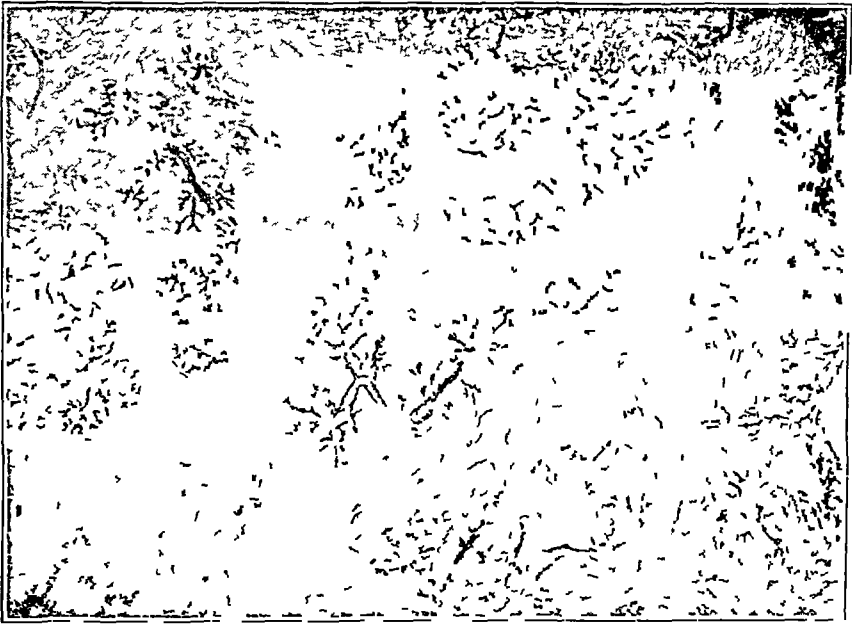


Fig 16—Necropsy specimen from normal breast of W F, married woman, aged 26, no history (From the Philadelphia General Hospital)

way, the differing conditions obtaining in different parts of the same breast, and the differing conditions obtaining in different parts of the same lobule, occasion dissimilarities in the histologic structure of different parts of the same breast, and of different parts of the same lobule. It is, therefore, not a simple, but a complex, series of events that characterize involution, with resulting different appearances, some of which prove very perplexing because their origin was not understood, and they have been misinterpreted by the best pathologists.

The mammary lobule is a temporary and transitory structure that usually exists in a rudimentary form before pregnancy occurs, and is destined to disappear after lactation is ended. The rapidity with which the lobules disappear varies greatly. In one breast of a young

woman, 19 years of age, who had had a baby one year before, there were a few small lobules fairly well conforming to the textbook description, while in the other breast there was scarcely a single one. The parenchyma had disappeared without distinct lobular formation, and with the most bizarre appearances of acinar and ductile vestiges, difficult to describe, but well shown in the illustration. On the other hand, the breast of a woman, 87 years old, still contained a few structures that could be recognized as vestiges of the definite lobules of long ago. It is necessary, though, to recognize rudimentary lobules in the virgin, fully developed lobules during lactation, decadent lobules during involution, and vestigial lobules after the menopause.

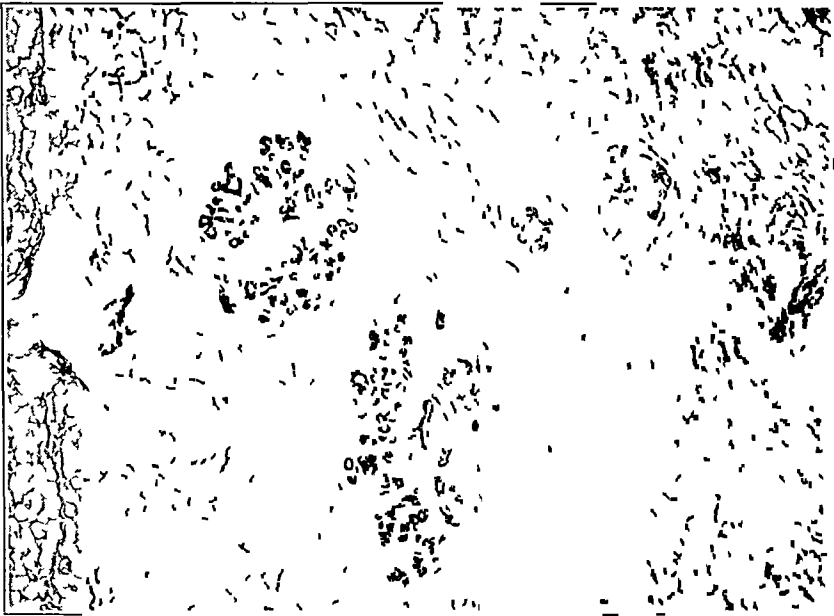


Fig 17—Specimen of normal breast from surgical case (A, B, white woman, aged 40), showing the typical textbook lobules that are supposed to represent the resting condition of the gland.

The general tendency of the mammary gland, therefore, seems to be to return to its virginal condition, and to contain nothing but ducts. The fulfilment of the tendency is, however, commonly interrupted by recurring pregnancies, and the complications interfering with involution to which reference has already been made.

Beginning with what seems to occur in cases in which involution takes place under most favorable conditions, and without complication, the sequence of events seems to be somewhat as follows. The acini of the lobule being empty and no new secretion being produced to fill them, they yield to the pressure of the elastic tissue in their walls and contract to a smaller and smaller size until the lumen can no

longer be seen. At about the same time, the cytoplasm of the epithelial cells seems to shrink until it becomes difficult to see. In the meantime the periductal tissue which becomes visible again as the epithelial elements cease to preponderate over it in importance shows multiplication of its nuclei. The result is a remarkable nuclear appearance of the lobule, whose other elements have become so obscured that they are no longer recognizable. So similar are the nuclei arising in the periductal tissue and those of the decadent epithelial cells that it may be impossible to determine to what kind of cell a given nucleus belongs. The epithelial cells undergo progressive extinction, beginning, to all appearances, with those of the peripheral acini, and extending toward the ducts which persist as the alveoli of the classical lobule. With

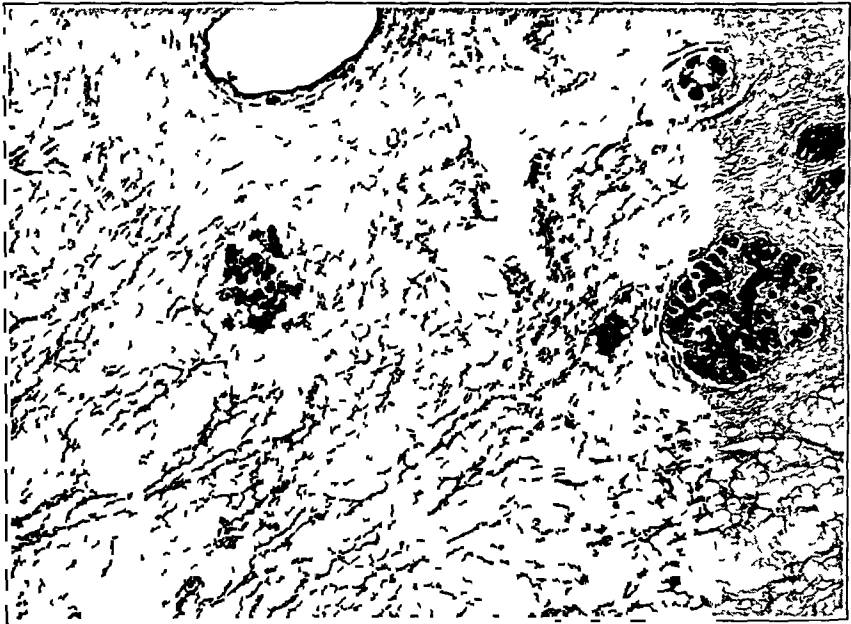


Fig. 18 — Specimen from the same breast as in Figure 17, showing, to the left of the center, fat deposited in the perilobular tissue. This is very rare in the human breast but it is the chief mode of assisting in the removal of the excessive parenchyma in the rat after lactation has ended.

the disappearance of the epithelial cells, the lobule loses a great deal of its nuclear appearance and comes to resemble more closely the classical lobule, except that the periductal tissue seems to be in excess, and usually irregularly distributed, loose and nuclear. As time goes on, the periductal tissue becomes more and more condensed or differentiated and the alveoli compressed. The latter grow smaller and smaller, and one by one disappear, as the whole lobule shrinks more and more. Eventually, the once large lobule is represented by a minute congeries of alveoli surrounded by a very small amount of, or perhaps by no distinctly recognizable, periductal tissue and a mere vestige of

a lobule (vestigial lobule) In the course of time these also may disappear, and the only parenchyma to be found in the breast may be its ducts In cases with complicating conditions, things may progress differently

The simplest form of complication is conceived to result from the continuance of the function of secretion by some of the acini after the greater number have ceased, a greater and more disturbing complication than that which results from the retention of secretion in the ducts This kind of interruption of involution may affect all of the acini of a lobule, but far more frequently only a few of them When it occurs, the unaffected acini undergo the changes

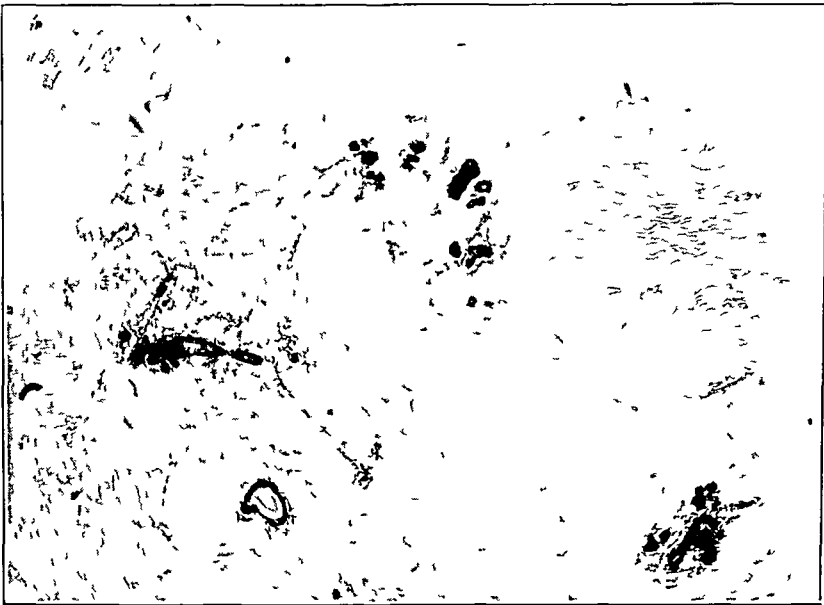


Fig 19—Necropsy specimen from the normal breast of J H, white woman, aged 58, showing uncircumscribed vestigial lobules in the postlactation breast The stroma of this breast was highly mucinoid and but slightly fatty (From the Philadelphia General Hospital )

already described, while the affected ones remain dilated and their cells unchanged The subsequent events seem to depend upon the duration and permanence of the acinar dilatation Beginning with cases in which the secretory function soon ceases, or the detained secretion escapes, it is found that the emptied acini, instead of retracting and contracting, now collapse, their opposed surfaces falling together, so that the formerly rounded spaces become fissures or crevices in the cellular area representing the lobule In such cases, which by the way are rare, the whole lobular parenchyma seems sometimes to undergo disappearance by softening beginning in the more centrally situated

portion, and extending peripherally, resolving itself into more or less unrecognizable débris, which when later removed leaves an irregular space

But when the secretory function persists, or obstruction prevents the escape of secretion already within the acini, the undilated acini in the lobule follow the usual plan of involution, while those that are dilated remain unchanged as long as the secretion is present, or at least until the periductal increase, which seems to lead to, or assist in, the parenchymatous extinction, is completed, and one of the prime factors in involution has disappeared. The result is the frequent presence in lobules, otherwise well advanced in involution, of single or

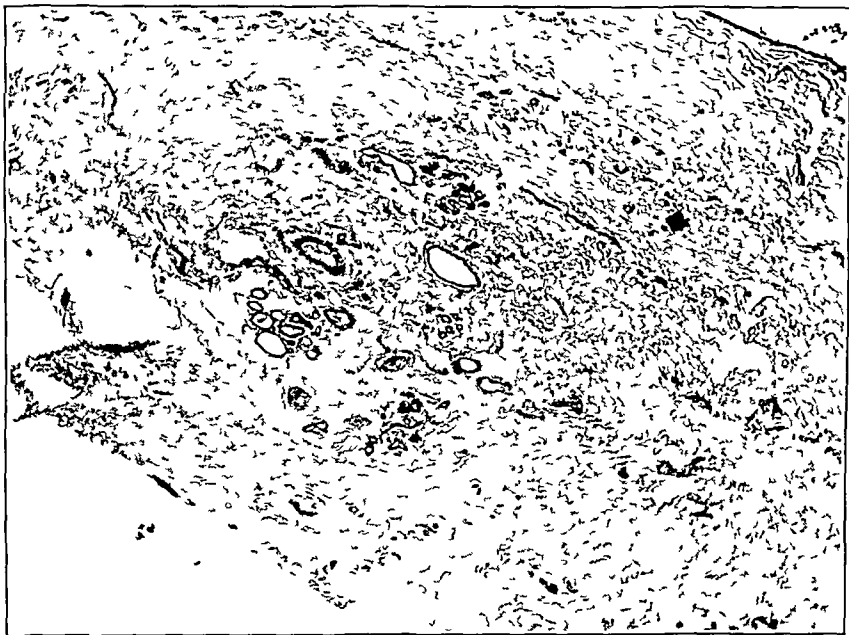


Fig 20—Necropsy specimen from normal breast of F B, aged 62, white, widow, showing uncircumscribed vestigial lobules in the breast after the menopause (From the Philadelphia General Hospital)

multiple rounded spaces, usually appearing at the edges of the lobules in the beginning, but projecting from the edges as they grow smaller, and eventually becoming entirely separated from them, though still in approximation to them as their disappearance progresses. Though the acinar epithelium elsewhere disappears, and assumes in the alveoli, which represent its only surviving remnants, a crowded and indefinite arrangement, that lining these residual acini retains much its original character and appears as a single layer of distinctly cuboidal, or, even in some cases, almost columnar cells, possessed of considerable cytoplasm. Such structures are present in many sections of mammary glands, and are commonly looked upon as sections of ducts, or groups of ducts.

The occurrence of such acini, in varying degrees of moderate dilatation, among others naturally retracted and extinguished, causes a peculiar form of lobular disruption, that constitutes one of the most striking signs of past lactation. They may be described as uncircumscribed lobules.

The peculiar behavior of the periductal tissue and the relatively large quantity of it that appears at the time of involution lead to the conclusion that it plays an important part in the extinction of the epithelium. Appearing as a highly cellular and excessively nucleated tissue, it soon passes beyond the nucleated stage, and becomes fibrillar. Its quantity varies greatly in different cases, that is, in the breasts



Fig 21—Necropsy specimen from normal breast of C R, aged 84, white, widow. There are no lobules, but their former position is indicated by epithelial lined fissures surrounded by condensed connective tissue formed by mixture of periductal and perilobular tissue. The relation of the interlobular tissue to this altered perilobular tissue is well shown. (From the Philadelphia General Hospital.)

of different persons, in the different breasts of the same person, in different parts of the same breast, and in different parts of the same lobule.

In what may be regarded as typical cases it is not strongly in evidence, and the typical textbook lobule results from comparative uniformity in its distribution, but from this it passes through every intermediate step to cases in which it is so excessive as to suggest beginning periductal fibroma. In some cases it presents a mucoid appearance, that is, its fibers seem to be separated widely by some

intermediate translucent substance, as in embryonal tissue. Under these conditions it becomes striking, giving the decadent lobule a great size and exaggerated importance. Like the epithelial elements of the parenchyma, however, it seems doomed to final extinction, and it is easy to determine the truth of this by the examination of a series of breasts of women that have passed the menopause, in not one of which are excesses of the periductal tissue to be found. In very rare cases fat cells penetrate into the periductal tissue.

Its final disappearance as an important structure seems to take place by contraction, by rearrangement and by confusion with the perilobular tissue. For a long time, it is a distinct entity surrounding the

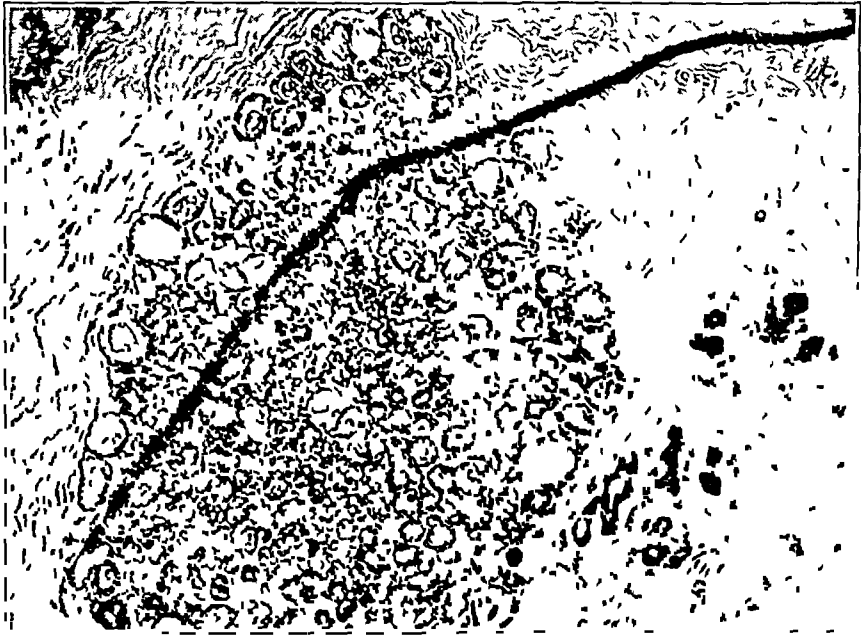


Fig 22—Necropsy specimen from breast of L J, colored woman, aged 19, who died of hemorrhage from ruptured ectopic pregnancy in the third month of the second pregnancy. The section shows a new lobule developing to the left of an old one in advanced involution. (From the Philadelphia General Hospital.)

alveolar elements, sharply separating itself from the perilobular tissue and making a sharp boundary for the lobular structure. As the lobules, however, more and more completely disappear in the breasts of the aged, it becomes less distinct, blending more and more with the perilobular tissue, until it may be difficult to define. There are cases in which the breasts of old women contain small, regularly formed atypical parenchymatous structures that may be either rudimentary or vestigial structures.

In estimating the rapidity of involution, and noting the disappearance of the lobules after the menopause, allowance must be made for

certain circumstances that seem to play an important rôle in their extinction, namely, the age at which the last child was born, and the number of children the woman has had. Thus, accepting 47 as the average age at which the menopause occurs, some women have their last child but a year or two before, others as many as twenty-five years before. In the former case there will be large quantities of parenchyma to be got rid of, at the age when the greater part of it should already have disappeared, and when some exhaustion of the force of involution might be expected.

Occasional breasts contain large lobules years after the menopause, and in some cases small lobules as well as vestigial lobules can be found until old age. The facts as given above, however, apply to the average

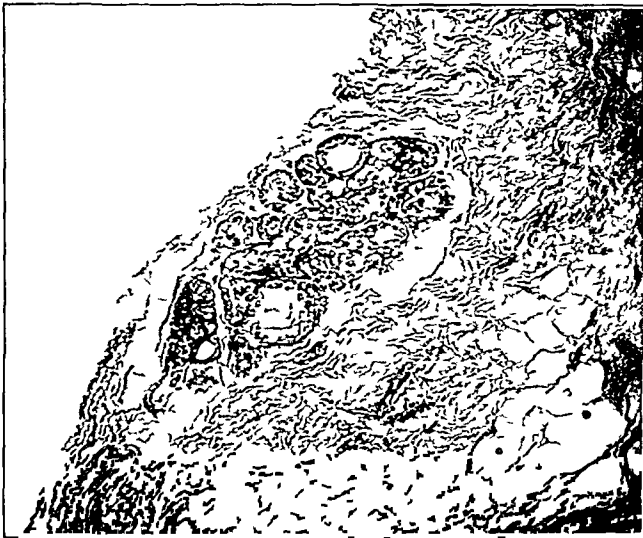


Fig 23—Necropsy specimen from normal breast of M. A., white woman, aged 87, married, showing a small lobule composed of residual lactation acini, with degenerated eosinophilic cytoplasm of the remaining epithelial cells. Many of the cells are without nuclei, and some have become fused into ill-defined masses. All of the remaining parenchymatous elements in the breast showed the usual staining quality. (From the Philadelphia General Hospital.)

case and the conclusions are based upon the careful study of fifty-four breasts of women, more than 47 years of age.

Before dismissing the subject it is necessary to point out that the rapid growth and excessive development of the periductal tissue seem to be a function of youth and that involution seems to progress much more rapidly at that time than in later life.

It is possible that with each successive lactation a new group of lobules evolves and declines. It is usually taught that the second, and later, lobular developments are through the resurrection of the alveoli that have previously entered upon the "resting state." This may need



confirmation It is sometimes possible to see in the breasts of those that have died early in a second, or later, pregnancy the newly forming lobules, as well as the relics of the antecedent ones In one such case the new acini were seen forming in close juxtaposition to an old lobule, but seemed to be quite independent of its structure

It may be, therefore, that the lobule having once performed its function declines toward final extinction, new parenchyma for each lactation being formed, as the preceding parenchyma was, through budding from the ducts

The most striking appearances observed in the course of mammary involution result from the survival of some of the lactation acini These

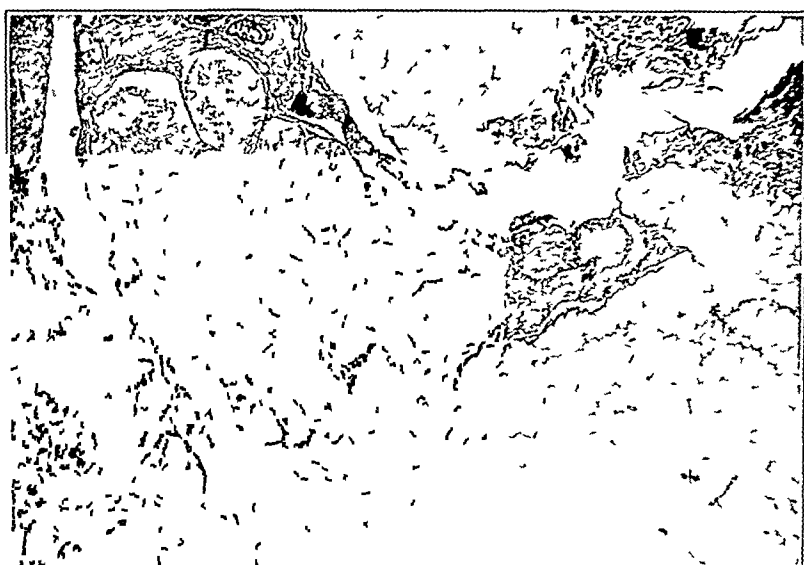


Fig 24—Necropsy specimen from normal breast of M E, colored woman, aged 55, married, twice pregnant The only lobule composed of residual lactation acini is shown in the illustration It showed highly atrophic eosinophilic epithelial cells, with scarcely any intermediate or surrounding periductal tissue There was scarcely any dilatation of the acini All the other glandular tissue found in the section had followed the usual type of involution (From the Philadelphia General Hospital)

will be spoken of as residual lactation acini They are of frequent occurrence, present a variety of appearances, and have been the subject of various and erroneous interpretation, the most important of which is the supposition that they are the beginning of tumor development

#### RESIDUAL LACTATION ACINI

The residual lactation acini are undoubtedly known to all surgical pathologists and have attracted much attention, but few pathologists have busied themselves so much in endeavoring to determine what they

are, as in determining what they might do. It was in reality the latter question that was the starting point of the present investigation. But before it was possible to answer that question it was necessary to find out what they were. It seems, therefore, best to continue the consideration from that point of view.

They are well recognized entities in cases of cancer of the breast, and occur in such close relationship to the cancer nests as easily to have led to the supposition that they are its starting point. They are not infrequently pointed out as the precancerous condition—"precancerous stage of cancer." They are also frequently found in normal

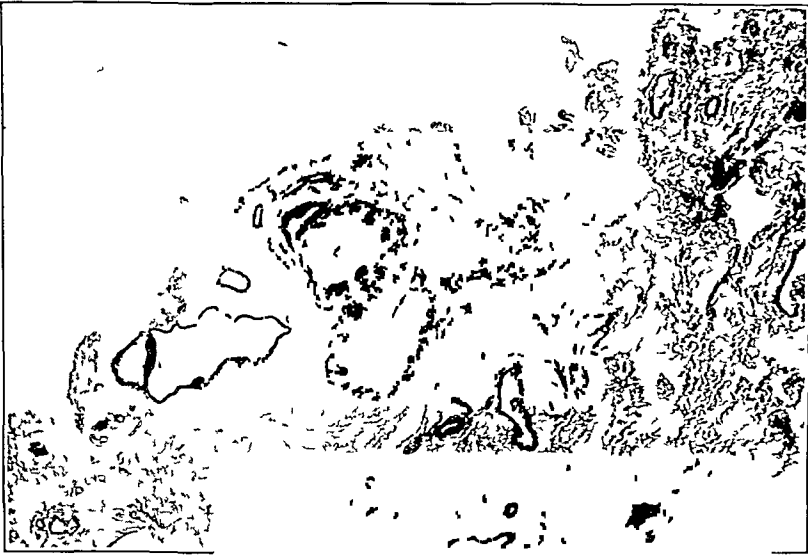


Fig. 25—Necropsy specimen from normal breast of E. R., aged 72, white, married, mother of one daughter. Two minute cystic residual lactation acini, from the walls of which short rounded stumps of preexisting interacinar septums project. These consist of irregularly cuboidal or columnar epithelial cells, amalgamated into coalescent masses in some of the knobbed processes, and show markedly eosinophilic cytoplasm. The nuclei, when preserved, stain uniformly and intensely. (From the Philadelphia General Hospital.)

breasts, then suggesting other and different explanations, as, for example, Krompecher's theory that they are aberrant sweat glands included in the mammary structure. It seems as though all of these opinions are but the result of inadequate knowledge of the process of involution and the many different appearances to which it may give origin.

In the present research all of the appearances presented by normal breasts collected at necropsy have been carefully collected, arranged in a series that is supposed to express the whole sequence of events in involution, complicated as well as uncomplicated, and in this series

these curious residual lactation acini have their regular place. It has already been pointed out that occasional acini, singly or in groups, sometimes fail to undergo involution at the regular time because of complicating circumstances. It next becomes necessary to determine what becomes of them.

When a single acinus is thus disturbed, it soon appears in a marginal position because of the disappearance of its fellows, and may even seem to be an entirely separate and independent entity of ductlike appearance, groups of acini meeting the same fate appear as approximate ducts, and may be passed by the microscopist without arousing interest. It seems possible that occasional structures of this kind may



Fig. 26—Necropsy specimen from normal breast of E. K., white woman, aged 59, married, no additional data. The specimen shows a group of residual lactation acini with marked projecting stumps of atrophic interacinar partitions. The epithelial cells lining the spaces and covering the stumps are columnar in shape and highly eosinophilic. They are distinctly atrophic, and confluence of approximated cells is frequent. (From the Philadelphia General Hospital.)

disappear, or if they were widely dilated, may contract, and substantially change their appearance, the lining epithelial cell layer being thrown into wrinkles, and the cells crowded and compressed so as to appear to be present in several layers, to be elongated, columnar and, in rare instances, of spindle shape. On the other hand, the space may undergo further dilatation through the addition of fluid contents, until a microcyst is formed. Under these circumstances the space becomes surrounded with flattened epithelium. They usually escape much attention, being supposed to be dilated ducts.

If instead of single acini, groups of them or considerable parts of the lobule become residual, a different appearance results. Atrophy, either as a manifestation of the general process of involution or from the pressure exerted by the dilated spaces, may cause the interacinar septums to disappear, and the neighboring spaces to coalesce into a larger space, either regular in shape if filled with fluid, or irregular if partly empty, and made peculiar and striking in appearance by the presence of relics of the former partitions that remain projecting from the margins in the form of stumps that may be simple and suggest folds or wrinkles, or complicated and suggest papillary excrescences. So long as the lining epithelial cells are not substantially altered, even these may be overlooked, or regarded as evidences of unimpor-

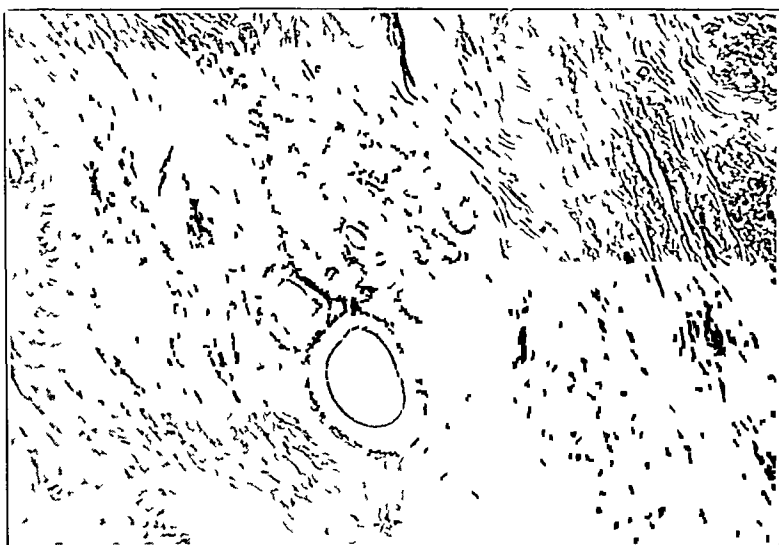


Fig 27—Necropsy specimen from normal breast of A W, colored woman, aged 40. Nothing concerning the personal history of this patient could be found out. Her breasts, however, showed such quantities of parenchyma in advanced involution that there seemed to be no doubt of antecedent lactation. The irregularity of involution and the delay in the atrophy of a few acini of a lobule are well shown, as is also the thinned interacinar partitions, some of which seem to be rupturing. In this case the epithelial cells had not yet assumed the eosinophilic quality that comes with advanced atrophic change. (From the Philadelphia General Hospital.)

tant proliferation of benign character. But if, as so commonly happens, the cells take on a highly eosinophilic staining quality, the whole formation becomes so striking in appearance as to excite interest and give rise to speculation. Such spaces, lined with eosinophilic epithelial cells, seem occasionally to retract, their crowded cells becoming compressed, assuming either a columnar or the spindle shape. The cells may also occur in several layers, the acini may continue to dilate, and the interspaces to attenuate until neighboring acini of large size

become separated by mere shreds of interacinar connective tissue, with epithelial cells on either side. These later attenuate to the point of rupture, when neighboring spaces coalesce with the formation of cysts. It makes no difference whether the rupture of the partitions comes early, while they are relatively thick, or later when they are thinned by distention, the end-result is the same. There is, in either case, the formation of a larger space into which the vestiges of the original partitions project as stumps, covered on both sides with the same eosinophilic epithelium that originally lined the acini. In a few cases the spaces collapse, their walls fall together, and there result slitlike spaces of elongated shape, like empty ducts.

More frequently, however, the spaces continuously dilate until they become cysts, varying in size from visibility to several centi-



Fig. 28—Necropsy specimen from normal breast of A. C., white woman, aged 55, married, showing a group of residual lactation acini. The partition walls are extremely attenuated and some have ruptured, leaving stumps projecting. Eosinophilia was just appearing in some of the cells in this area. (From the Philadelphia General Hospital.)

meters in diameter ("blue domed cysts" of Bloodgood), in the beginning lined with high columnar eosinophilic epithelium, sometimes in several layers, later with cuboidal cells, still later with flattened cells, and finally without distinct cells of any kind.

The varying appearances presented in different cases and at different times by the residual lactation acini, may be arranged serially as follows:

1. Single acini, or groups of acini that differ from their fellows in the same lobule, in that they escape involution and remain dilated

2 Similar structural units, remaining at the edges or near the periphery of lobules well advanced in the process of involution. They are lined with single or multiple layers of epithelial cells like those of the acini in general, though sometimes the cells are more columnar in shape and more crowded.

3 Similar units, with all of the described qualities, occurring in the perilobular tissue, and seemingly apart from any lobules.

4 Groups of such units, the individual members of which are separated from one another by considerable intervals of fibrillar connective tissue.

5 Groups whose members are separated by narrow intervals, scarcely consisting of more than a double row of epithelial cells.

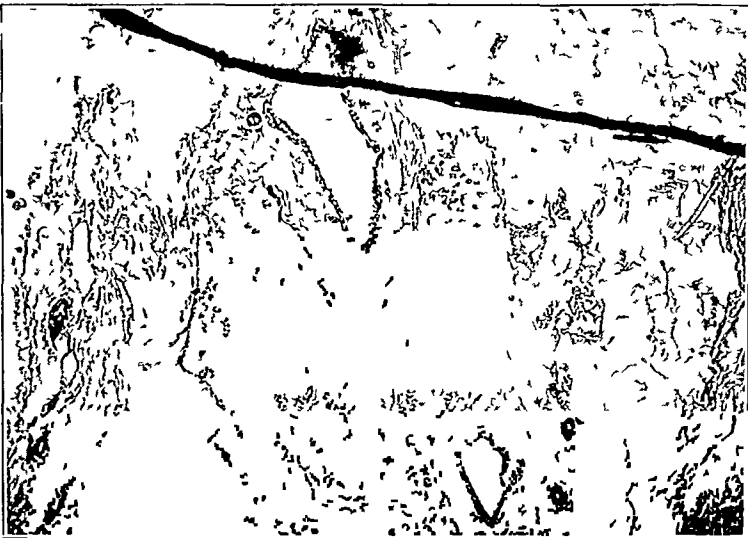


Fig. 29—Necropsy specimen from normal breast of B. D., white woman, aged 75, married, showing three residual lactation acini very indistinctly, because the eosinophilic quality of the cells was so marked as to make it difficult to photograph their red bodies. The partitions are thin but have held, and there are no stumps. The spaces give the impression of partial collapse. (From the Philadelphia General Hospital.)

6 Groups in which the contraction of the space crowds the epithelial cells and causes them to encroach upon the lumen, with an appearance of proliferation.

7 Groups in which distention of the space results in the formation of microcysts, with various epithelial cell linings.

8 Groups in which the epithelial cells early acquire an eosinophilic staining quality, and a relatively large size. Such quality may characterize any of the groups previously mentioned.

9 Groups of any of the foregoing in which the atrophy of the intermediate partitions between the units causes them to coalesce.

10 Groups of such kind in which the stumps of the partitions remain projecting into the common space, covered with epithelium of the same quality as that which lines the spaces

11 Cystic dilatation of such coalescent acinar spaces, with gradual obliteration of the projecting stumps of the original interacinar spaces

12 Cysts that may be several centimeters in diameter, formed through the dilatation of single or coalescent acini of any of the forms mentioned

13 Irregular crevices or spaces in the tissue of the breast that follow atrophy of the interacinar partitions and collapse of the acini

Thus, the careful study of what is to be found in the normal breast in its various stages of involution, and the arrangement of the peculiar modifications of the process of involution in series, leads to



Fig 30—Necropsy specimen from normal breast of F B, aged 68, white widow, showing several residual lactation acini, the larger with stumps of atrophied interacinar septums projecting from the upper side. The scanty epithelial lining was highly eosinophilic in quality and cells had frequently coalesced (From the Philadelphia General Hospital)

the inevitable conclusion that the "Schweiszdrusen" of Krompecher, the "cyst-adenoma" of Schimmelbusch, the "senile parenchymatous hypertrophy" of Bloodgood, the "abnormal involution" of Warren, the "secondary epithelial hyperplasia" of McCarthy, etc., are no more than variations in the involutional process, in which residual lactation acini appear in various conditions of retrogressive change

One of the first to call attention to the presence of the residual lactation acini, and to connect them with the process of involution, seems to have been Charles Creighton, in his book "Contributions to the

Physiology and Pathology of the Breast," published in 1878. He, however, made the error of supposing that they were abnormal, and, as others have ever since done, assumed that they were the starting point of malignant tumors.

Creighton saw the changes in the mammary gland of a bitch, and as it seemed to him to be a striking variation from the normal, concluded that it must be abnormal. Had he studied many, instead of a few, glands, he might have come to a different conclusion.

But this brings up the pertinent question of its normality or abnormality. The mammary glands that formed the material for this



Fig 31—Surgical specimen from the breast of a married woman of whose personal history no data could be obtained, showing the smallest of a group of small cysts. The organ was supposed to be cancerous, but no disease was found. The irregular epithelial lining shows well, and the stumps of the former interacinar septums are numerous. All of the epithelium is highly eosinophilic, many of the cells are shapeless, and some have coalesced. The debris seems to be composed of eosinophilic cell remnants.

research were, as nearly as could be determined, normal, that is, they were taken at necropsy from organs seemingly normal, and from the bodies of those that had not complained of breast troubles during life. The authorities of the hospital from which most of the material was obtained do not permit the mutilation of bodies upon which



necropsies are performed, and are strict about the number and character of the incisions permitted, so the removal and examination of the entire breast was not possible. Fragments alone were obtained for examination, removed from the back of the breast exposed as the tissues were dissected from the chest wall. In most cases the amount of tissue was small, and selected without any definite purpose in view. A more thorough exploration might have afforded added opportunity of demonstrating the presence of the residual lactation acini. But of the material obtained in this somewhat haphazard fashion, twenty-three of the 150 mammary glands showed their presence—15.33

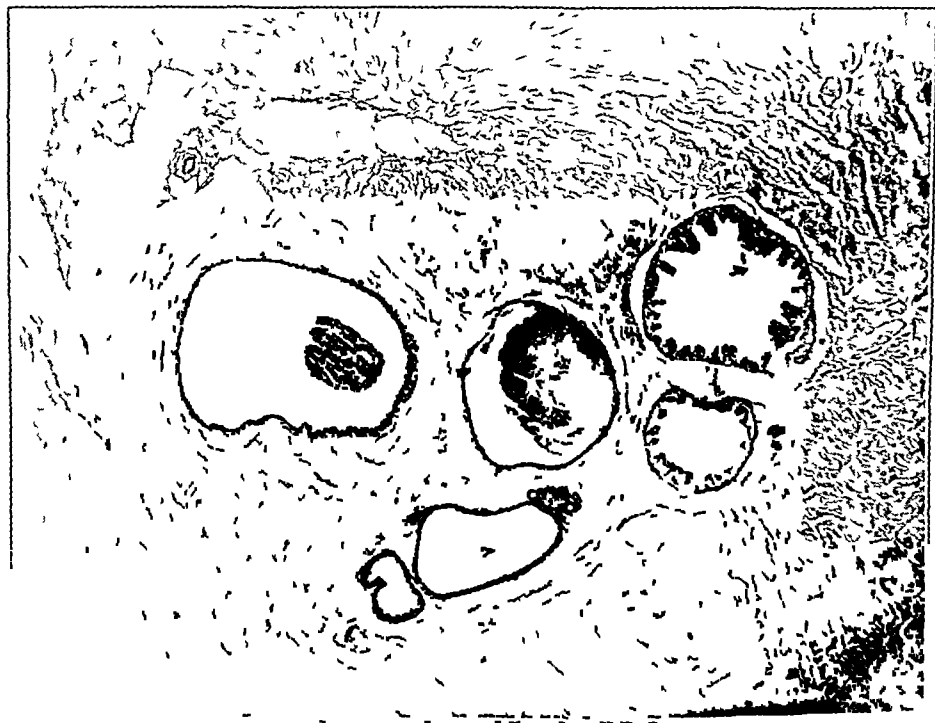


Fig 32—Necropsy specimen from normal breast of A. McL., aged 66, white, widow, with one child, showing a group of microcysts. Two of them, on the right, show interacinar stumps and have eosinophilic epithelium. (From the Philadelphia General Hospital.)

per cent. Is that to be regarded as abnormal that occurs in such a large number of cases?

But inasmuch as a number of the cases were inappropriate for the discovery of the residual lactation acini because the women from whom they were taken had never lactated, the percentage rises when it is based upon the cases in which it ought to appear. Among the 150 cases, there were ninety-two in which the women were known to have been married or to have had children, and of these the residual lactation acini occurred in twenty-three, or 25 per cent. Thus, it seems

that one fourth of the women whose breasts have been functionally active show this modification of involution, even though the examination of their breasts was superficially made. The average age of the women in whose breasts residual lactation acini were found was 59 years. The youngest was 33, the oldest 103 years.

But the final confirmation of the theory rests upon the demonstration of residual lactation acini in the breasts of women that have been pregnant, and their constant absence from the breasts of others. This requirement it is impossible to fulfil because of the impossibility of



Fig 33—Surgical specimen showing a group of cysts, distinctly visible to the naked eye, in relation to the involuted lobule from whose dilated elements they sprang. These cysts have smooth walls.

accurately determining who had and who had not been pregnant among women, some of whom may for a variety of reasons conceal or deny it.

The following plan seemed to be an appropriate means for reaching the truth as nearly as possible.

I. The determination of the percentages of married and single women among the cases of normal breasts secured at necropsy, in which the residual lactation acini were found. The results were cases, 23 married, 23—100 per cent single, 0—0 per cent.

age at which the individual became pregnant would affect it. Repeated pregnancies obscure the picture, through the introduction of new lobules, if they do not revive already existing ones. The time at which the involution process is begun must have great influence, because of the varying quantities of parenchyma to be dealt with. Thus, in cases of abortion or miscarriage, complete lactation hypertrophy does not occur, and involution begins in a gland only partly evolved. If the child is born dead, or if the mother refuses to nurse it, though the parenchyma be fully formed, it may not reach full secretory activity and more easily undergoes involution than when it has secreted. If the secretion fails, the acini will perhaps be empty, and, the infant being artificially fed, the breast undergoes involution unimpeded by



Fig 36—Specimen from normal breast, surgically removed, of A B, aged 40, white, single, showing area of residual lactation acini which was found among normally appearing lobules of the textbook variety. The rupture of numerous interacinar partitions is shown. When such rupture occurs the cells are more highly eosinophilic than elsewhere, but the preservation of the area is too perfect to permit much eosinophilia. In various places the interacinar stumps are distinct.

accumulations of its own products. In any case the drainage of the mammary tissue may be unequal in different parts, and those that empty completely may atrophy more quickly than others in which some secretion is retained. So many factors thus combine to complicate the process in human beings that it is difficult to arrive at any conclusion, especially when to all these there must be added the inability to obtain precise information regarding the history of the patient.

But what is known is that in some cases, as that of the young woman of 19 years, to whom reference has already been made, most of the parenchyma had disappeared within a year after the birth of her baby, while in others, it remains for many years. In one case, that of a woman whose history is well known, the second child was born when she was about 27. At about 43 a breast was removed for "abnormal involution with suspicion of cancer." In it a tiny scirrhous carcinoma was found, entirely too small to have been recognized clinically, and all stages of mammary involution were found, among them a few lobules that still showed unchanged lactation hypertrophy resembling that seen in the fully acting breast, sixteen years after lactation. Between them and advanced involution of the lobules

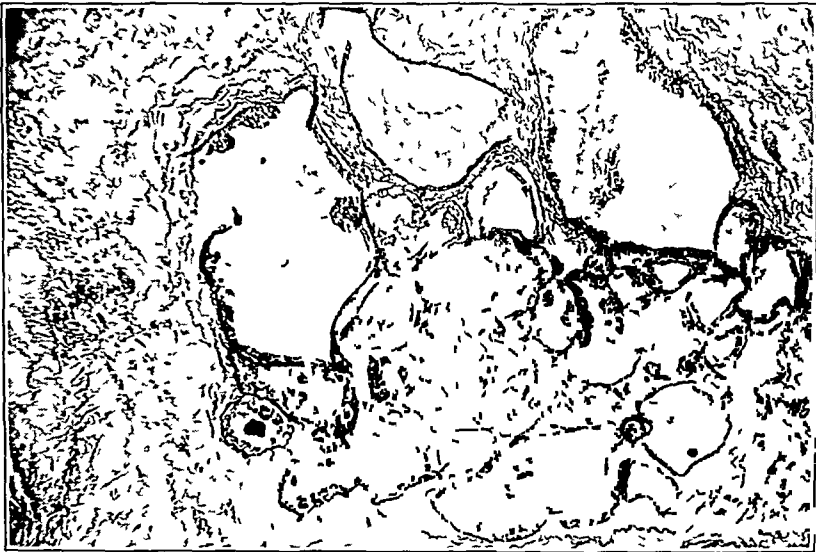


Fig 37—Necropsy specimen from normal breast of E H, aged 60, white, married, one child. This beautiful area of residual lactation acini was somewhat injured in preparation, and was too highly eosinophilic to photograph well. It shows all stages from fairly well preserved acini to cystically dilated spaces without epithelial linings. Some of the spaces, such as that at the lower left, show interacinar stumps covered with highly eosinophilic cells. (From the Philadelphia General Hospital.)

there was every intermediate stage. What caused these lobules to remain unchanged throughout all those sixteen years could not be determined.

Seeing that a few or many of the mammary lobules may thus remain exempt from involution for so long a period, and that in many cases involution is very slow, it is not surprising that through delay in the involution of occasional units of the mammary structure the residual lactation acini may appear. Nor, having appeared, ought it be regarded as remarkable that they may persist.

But with the lapse of time they are likely to undergo certain changes. One of the earliest and most striking of these is the occurrence of the eosinophilic quality of the cytoplasm of the cells. In some cases this seems to make its appearance early, in others, late. Naturally, this is only a deduction, not a demonstrated fact, and is based upon the observation that it may occur in acini situated in the midst of lobules in an early stage of involution, at other times in groups of acini whose surroundings show them to be old, and in aged women.

In many cases, accumulated products of degeneration may be observed in the spaces formed by the coalescence of closely approximated acini, evidently composed of the detritus of the desquamated and disintegrated epithelial cells set free by the wasting and rupture

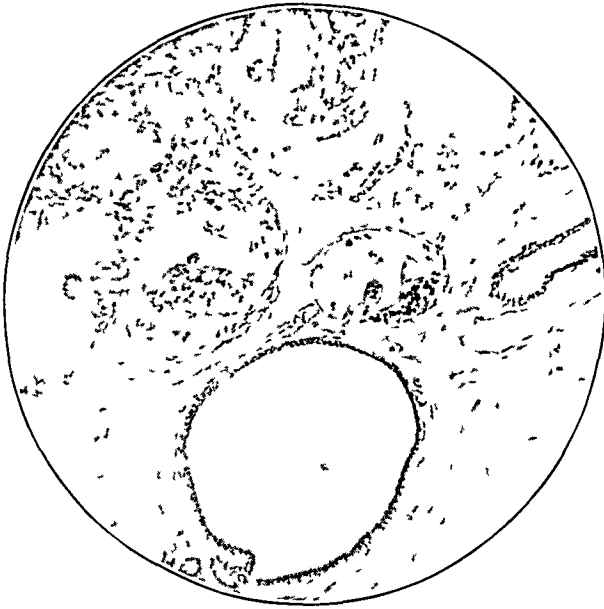


Fig 38—Specimen from a woman's breast, surgically removed and suspected of being carcinomatous. No other data available. No tumor of any kind was present, but several areas of residual lactation acini were found, one of which is shown in the illustration. The atrophy of the interacinar partitions is marked, and the eosinophilic quality of the epithelial cells well developed. The area shown in the illustration shows unruptured partitions, stumps of ruptured partitions, and amalgamated masses of cells.

of the interacinar partitions. The residual lactation acini differ greatly, however, in this respect. Many are empty, some contain a little, some are nearly filled with matter of varying quality, some like jelly, some granular, and some composed of pellets of amorphous matter, which in one case was found to have calcified, with the formation of laminated chalcospheres. Some of these accumulations may be as old as the acini themselves, and may have been the source of the obstruction to which the retardation of involution has been ascribed, but others are undoubt-

edly relatively recent. It seems, moreover, that to their presence may be referred the subsequent distention of the acini with the formation of cysts that seem to be of frequent occurrence. In regard to these it is not assumed that they act only or even chiefly as sources of obstruction, but as material whose transformation is accompanied by the formation of chemical products whose affinity for water leads to its accumulation with dilatation of the spaces. It is with the development of cysts of large size or considerable number that such cases become known to the surgeon from whom the patients seek advice, and by whom they are commonly operated on.

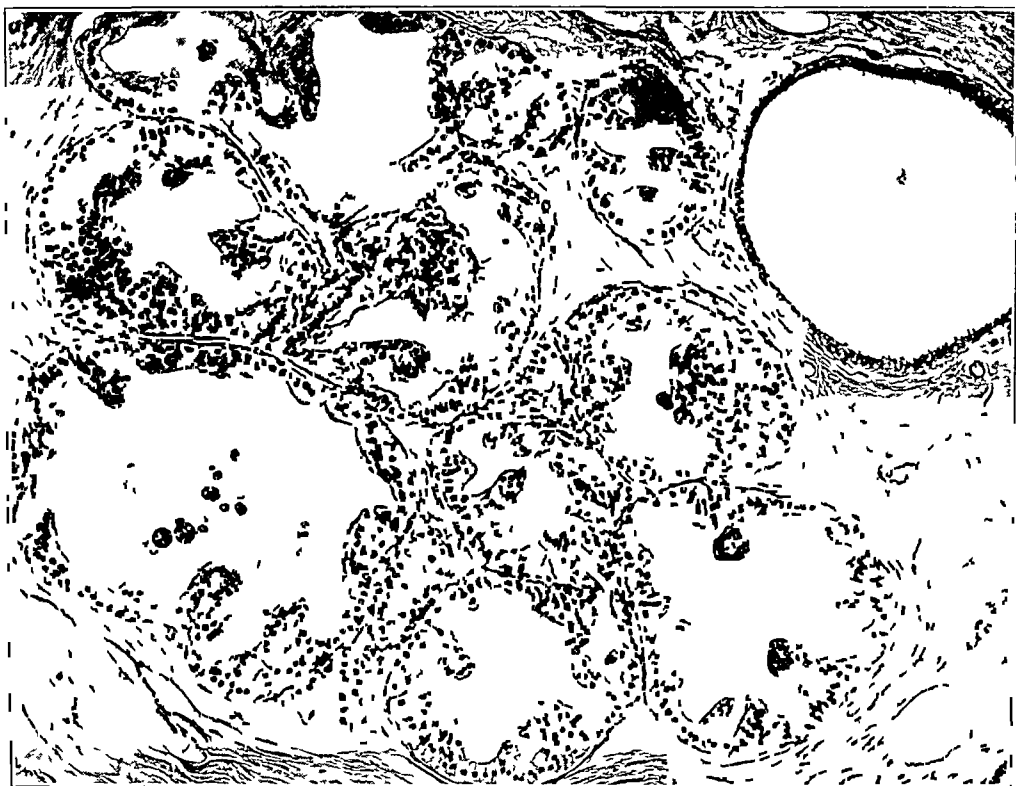


Fig 39—Specimen showing an area of residual lactation acini in a breast surgically removed for suspected cancer. No data concerning the patient was available. There was no tumor, and no other disease. The group of spaces is highly characteristic. Numerous acini are not much changed, others are united as the result of atrophy of the interacinar septums, relics of septums project in many places as stumps, some of which are reduced to budlike masses of amalgamated eosinophilic epithelial cells.

Since the term chronic cystic mastitis has been adopted by Bloodgood in his recent paper, it will be adopted here. Chronic cystic mastitis, though described in the textbooks, and elaborately discussed in many journal articles, is in reality a vague disturbance. The age at which it usually makes its appearance corresponds fairly well with the

child bearing period It is clinically characterized by vague discomfort in one or both breasts, which when examined are found to be tender and to contain one or several ill-defined indurations, or "lumps," which sometimes confuse the surgeon by seeming to be present at certain times and absent at others

It is pathologically characterized by cysts, occurring singly or in groups, surrounded by condensed stroma, in which mammary tissue in various quantity and different conditions is present One of its striking, but not invariable, characteristics is the presence of parenchymatous structures, like exaggerated acini, or ducts, lined with more or less distinct columnar epithelium, from the walls of which simple or



Fig 40.—Necropsy specimen of normal breast of T S, aged 40 colored, widow, said not to have had children, a statement which the histologic structure of the breast makes very doubtful The illustration shows one of the groups of spaces looked upon as residual lactation acini It is, however, in an advanced state of atrophy with destructive transformation of nearly all of the cells Projecting stumps with eosinophilic coalescent cells may still be seen in the space at the right edge (From the Philadelphia General Hospital)

dendritic projections extend into the lumina Such lobules as appear in the examined tissue commonly present inequality of the periductal tissue

Bloodgood's <sup>1</sup> article is one of the most masterly and comprehensive articles that have appeared on the subject, and is based on the macroscopic and microscopic examination of 350 cases—an overwhelming

1 Bloodgood, J C The Pathology of Chronic Cystic Mastitis of the Female Breast, Arch Surg 3 445 (Nov) 1921

volume of material, well studied, and well analyzed. If, however, he had not fallen into one of the most frequent errors to be avoided in pathologic work, that of comparing the cases with one another, instead of with the normal breast, the article would probably have been written in some other form, and the cumbersome nomenclature with which it terminates omitted.

Now when the findings in chronic cystic mastitis are carefully analyzed, and compared with the findings in the normal breast, they resolve themselves into very little, apart from the presence of the cysts. Taking first the condition of the stroma, it will be recalled that one of



Fig. 41—Section of a surgically removed breast, showing residual lactation acini similar to those seen in Figure 40.

the first observations made in the present research was that unless there was present some distinctive disturbance, such as round-cell infiltration, hemorrhage or calcification, nothing could be learned from its study because of the extreme variability of its normal structure. The presence of a growing cyst, pushing aside the fibrous tissue and causing atrophy of the adipose tissue, may give the stroma unusual density by condensation, but that is not chronic inflammation. The illustrations in Bloodgood's article show no disturbances that cause the stroma to differ from that seen in the normal breast.

When the periductal tissue is prominent and especially when it lacks uniformity of distribution in the lobules the condition is referred



to by Bloodgood as chronic cystic mastitis, but that is the condition of the same tissue in nearly all of the lobules of the normal breast. Nothing is shown as a pathologic change in this tissue that is not perfectly paralleled in the normal breasts that form the basis of the present research.

It must, therefore, be the parenchyma to which one is compelled to look for the specific changes. And here firm ground seems at first to have been reached, for there are many illustrations bearing the legend "papillary cyst-adenoma."

That designation for residual lactation acini has so frequently been dwelt on—not exactly that, but "cyst-adenoma"—that it immediately demands careful study of the illustrations to see how what is repre-



FIG 42—Necropsy specimen from normal breast of R. R., white woman, aged 54, married, showing a large lobule of residual lactation acini in which there has been very little atrophic change. The irregular slits in the parenchyma seem to be originally dilated spaces that have collapsed. The epithelial cells everywhere are in a fair state of preservation but are very pale, with pale vesicular nuclei, and slightly eosinophilic clear cytoplasm. The general appearance is like that seen in many cases shortly after lactation, except for the altered staining quality. (From the Philadelphia General Hospital.)

sented may differ from what has been the main subject of the present research. Comparison shows that there is no difference, they are the same. One is, therefore, compelled to question whether there is really anything to be found in these cases, except the cysts, that may not be present in the normal breast in some stage of its involution, with the inevitable discovery that there is not

Chronic cystic mastitis, therefore, seems to resolve itself into no more than the occurrence in the breast of cysts of larger than usual size after postlactation involution, the other associated disturbances being no more than errors of interpretation based on inadequate familiarity with the details of the involution process

It seems, therefore, that there being no mastitis in these cases, there can be no chronic cystic mastitis, and all that occurs is the presence of cysts of a size larger than that reached in the course of involution. But one matter of serious import is to be considered, and that is the emphasis laid on "adenoma," "cyst-adenoma" and above all on "papillary cyst adenoma" in Bloodgood's paper



Fig 43—Necropsy specimen from normal breast of E F, aged 56, white, widow, showing area of residual lactation acini in which the atrophic changes are further progressed than in Figure 42. The rounded space on the left still shows the skeleton of its acinar structure, while the irregular one on the right leaves one in doubt as to its nature. It might be either a completely transformed lobule or a duct filled with debris, such as must eventually result from further degeneration in the other. Scarcely any cells are recognizable except by their form and position, and all are eosinophilic. (From the Philadelphia General Hospital.)

The employment of these terms for the explanation of what could not be satisfactorily accounted for, namely, the dilated acini with their eosinophilic epithelium, and occasional mural papillary projections, termed, in this article, residual lactation acini, was first introduced by Schimmelbusch

It is probable that Schimmelbusch had just as inadequate information on the manifold appearances presented by the breast in involution as any other pathologist, and that he, therefore, made a mistake. But it is a pity that it should be perpetuated by continued application to appearances common to a large number of the mammary glands of human beings and animals during mammary involution.

Bloodgood goes farther and seems entirely to disregard the fact that the mammary glands of women that have recently lactated contain large lobules, and in his illustrations he applies the term "nonencapsulated adenoma" to nearly all of the normal mammary parenchyma that appears in his sections. Thus the reader is left with the impression that the mammary gland is peculiar in that it may be the seat of "encap-



Fig 44—Necropsy specimen from normal breast of J F, aged 75, white, widow, nine times pregnant. The residual lactation acini in this case are less distinct and less regular than those that have preceded it, and the cells lack the eosinophilic quality. The shape and general arrangement of the structure, however, leave one in little doubt as to its origin. (From the Philadelphia General Hospital.)

sulated" and "nonencapsulated" adenomas, the latter of which in no way differ in appearance from the normal mammary tissue, and of an uncircumscribed tumor, the "cyst-adenoma" which diffuses itself throughout the breast, or occurs at multiple foci.

Schimmelbusch's "cyst-adenoma" is a misinterpretation. It ascribes to the decadent residual lactation acini an importance of which they are unworthy, and leads to the belief that they are vital growing things, when the evidence is strikingly in favor of their being precisely the opposite.

From the examination of some single section, in which a group of the residual lactation acini are well preserved and provided, as sometimes happens with several rows of epithelial cells, or in which the collapse of the decadent acini causes crowding of the cells at particular points, it may sometimes be suggested that the appearances are proliferative, but after many cases have been studied, one becomes overwhelmed with the evidence to the contrary, manifested by the eosinophilic cytoplasm, the presence of anuclear cell remnants among the still living cells, the frequent desquamation of the cells without their regeneration, the contraction and condensation of many of the groups of acini, the necrotic residuum of amorphous matter that collects in the older lesions, and the general inactivity of the cells, and other fea-

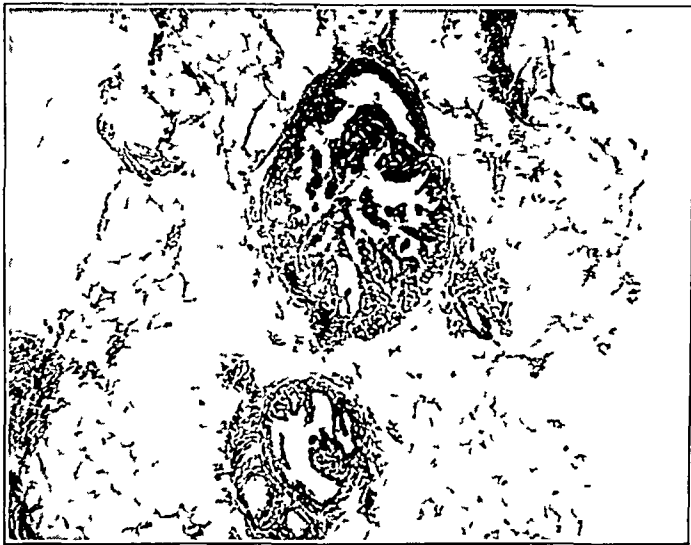


Fig 45—Necropsy specimen from normal breast of H J, aged 103, widow, showing vestiges of residual lactation acini of great age, but still with enough of the remaining skeleton of the original lobule to explain their source. The cells were so atrophic as scarcely to be recognizable and their remains were eosinophilic. Except for these few vestiges the lobular parenchyma of the gland had virtually disappeared. (From the Philadelphia General Hospital.)

tures not easy to describe. Beyond all this, there is the absence of any evidence, in spite of the study of many cases, to show that the formations ever do anything or develop into anything.

It is impossible, however, to neglect the papillary processes whose presence has excited so much interest and has led to the cases in which they occur being called "papillary cyst-adenoma." They certainly are peculiar and striking formations, but they, like so many others seen in connection with involution, have certain qualities by which their nature and origin are betrayed. As a rule they are few in number, simple in structure, do not interfere with one another, and not infrequently stand

opposite one another. These features are in marked contrast to other papillary excrescences—as, for example, those found in the cysts of the kidney and thyroid, where the number is usually large, the structure complexly branched, and the different formations crowded together so as to interdigitate.

The decadent quality of the eosinophilic protoplasm of the epithelial cells covering the processes, the adhesiveness that causes adjacent cells to coalesce, and the occasional occurrence of considerable masses of still separated ghosts of cells without nuclei, have already been referred to as far more indicative of retrogression than of vegetation. But the slightest effort of the imagination is sufficient to enable the broken

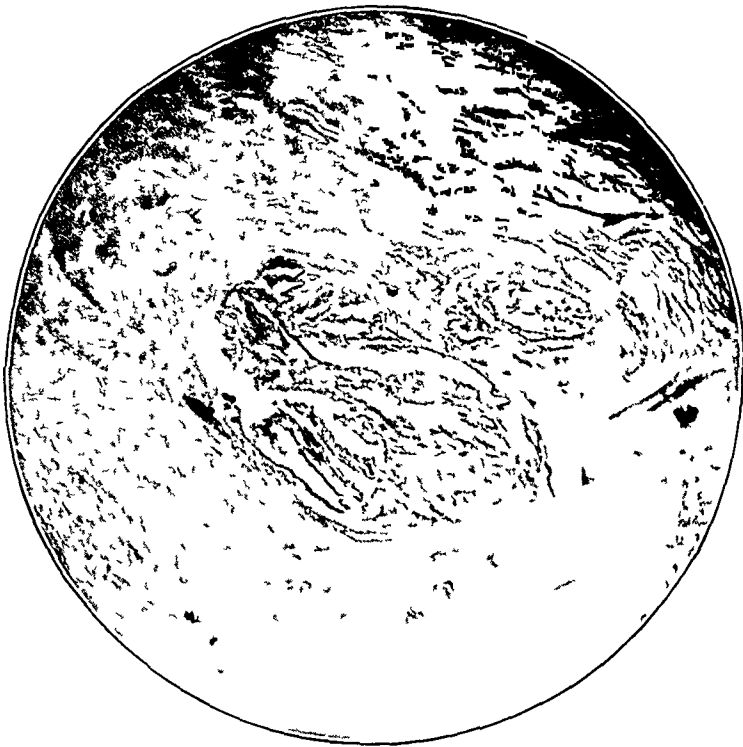


Fig 46—Specimen from a married woman, no history. In this lobule the epithelial cells have all disappeared, though the interacinar framework partly remains—a rare circumstance.

partitions to be reconstructed into the interacinar reticular framework, and the cystic space into an involuting lobule. There seems, therefore, to be good reason for abandoning the idea that in these residual lactation acini the first stages of tumor formation are to be seen, as well as the consequent fear that they may terminate in something malignant.

This now introduces the remaining question connected with the residual lactation acini, namely, the relation they may bear to cancer. The thought that they may originate cancer is widespread, and its origin not far to seek. The circumstance most feared in every dis-

turbance of the breast is "malignancy," and as its occurrence is very mysterious, and cannot be explained at present, the custom has been to examine every breast offered for study for such structural alterations and irregularities as might lead to it. Naturally, such striking objects as the residual lactation acini could not be overlooked, and there being no ready explanation of their meaning, they were gladly seized on as the probable starting point of tumor growth. In support of this view, the frequent concurrence of cancer with residual lactation acini was dwelt on. The cancer nests were shown to be in close juxtaposition to the formations of suspicious nature that were not understood, and it seemed as though the one might have developed through trans-

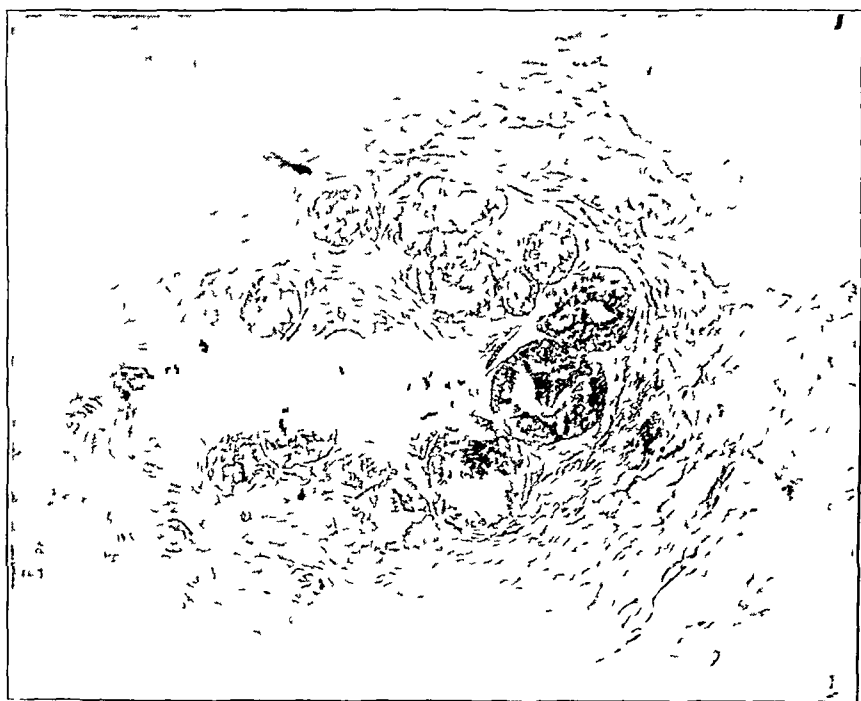


Fig 47—Necropsy specimen from normal breast of J C, aged 75, white, widow. This patient was a hemiplegic with a leg ulcer, and was in the Philadelphia General Hospital for a long time. She was so frequently transferred from ward to ward that there are many "charts," but the one with her personal history could not be found. In the lobule shown, the unusual increase in the periductal tissue interfered with the union of many of the residual lactation acini. (From the Philadelphia General Hospital.)

formation of the other. Cancer cells frequently appear in the acinar spaces among their own peculiar epithelium, and many have supposed that they were able to find the transition steps between the one and the other.

The almost universally accepted theory of mammary cancer of the present day teaches that the cancer cells arise through metamorphosis

of the mammary cells themselves—that they are but the lawless descendants of those cells. This may be true, but it is at present only a theory, never having been proved. No one has ever seen the beginning of cancer. But once a theory meets with acceptance, it becomes a fact to the complacent mind. It is more easy to accept it than to combat it, and if it seems satisfactorily to explain the condition, why upset it?

So firmly is the theory rooted in the minds of pathologists of the present day that it is by no means unusual for a microscopist, examining a section of a cancer to select a microscopic field, and to demonstrate

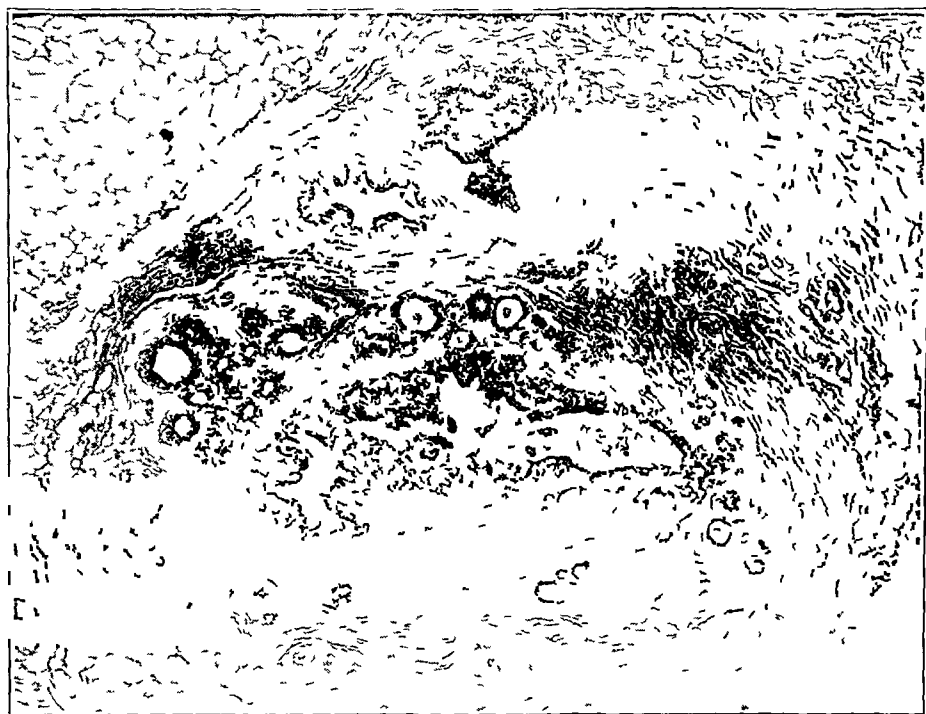


Fig 48—Necropsy specimen from normal breast of M. C., aged 51, white, married twice, had three children and two miscarriages. The menopause had occurred five years previously, her husband had died three years previously. As in Figure 47, the arrangement of the periductal tissue has modified the process of involution, and the destruction of the interacinar septums has resulted in the formation of an irregularly elongated space the margins of which, degenerated eosinophilic cells, and collections of cellular and amorphous debris betray its origin. (From the Philadelphia General Hospital.)

in it the primary rupture of the basement membrane of some glandular unit, from which the cells are escaping and beginning their lawless invasion. A moment's reflection ought to make him realize that such a demonstration necessarily implies that cancers have continuous and successive beginnings, for which there is no authority, since examinations by serial sections have repeatedly shown the entire cancer mass, with all of its extensions and prolongations, to be continuous.

In infiltrating cancer of the mammary gland it is really more reasonable to suppose that the cancer cells lawlessly and invasively penetrating the tissues are finding their way into the acini, than that the acinar cells are escaping to form the cancer. If the theory of "cyst-adenoma" is abandoned, and that of residual lactation acini adopted, the relation of the lesions to cancer can be examined without prejudice, and to advantage, for under these circumstances it will probably occur to the student that as most women become pregnant, and later nurse their offspring, the breasts of most women when examined microscopically must show parenchyma in some stage of involution, and as

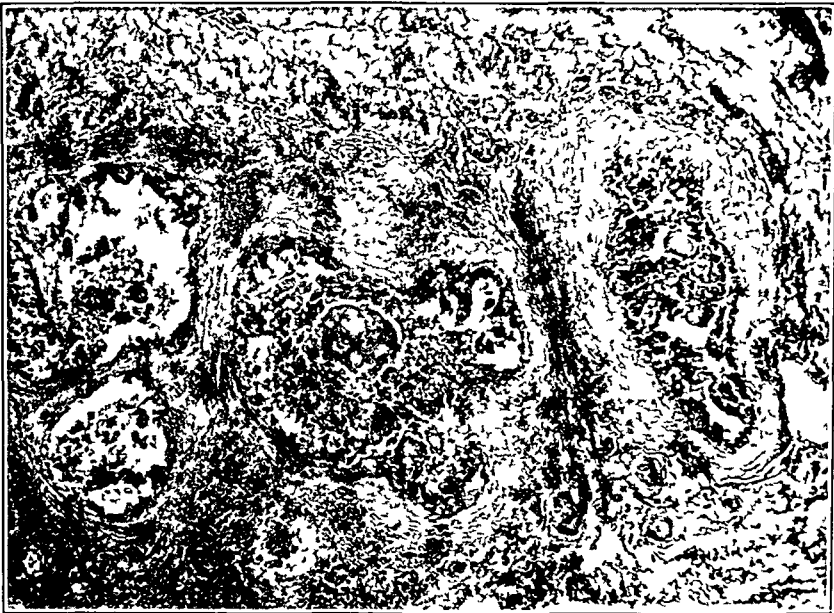


Fig 49—Necropsy specimen from normal breast of A. G., aged 40, colored, widow, showing residual lactation acini surrounded by rinds of combined periductal and perilobular tissue similar to that shown in Figure 21. The atrophy of the parenchyma is so complete that the origin of the peculiar spaces might remain inexplicable without the study of the series of cases by which it is preceded. All of the cells are in an advanced state of degeneration. There is no proliferation. The degeneration of the cells and partitions has led to the formation of transformation products of rounded amorphous, more or less hyaline, appearance in the spaces. (From the Philadelphia General Hospital.)

residual lactation acini are of frequent occurrence in consequence of lactation hypertrophy, at least one fourth of the breasts may contain them. It, therefore, ceases to be a matter of concern or surprise that a breast examined for malignant disease shall contain residual lactation acini, with or without cancer. The frequency with which each occurs determines that they must frequently coexist.



But it has been argued that the relation of the cancer to the residual lactation acini is too close to be accidental, it must be incidental. There are many more cancer cells in those spaces than elsewhere, and metamorphosis of the lining epithelium into cancer cells can be followed. The same thing has been argued with respect to the acini, the alveoli and the ducts of the mamma itself. In the absence of the residual lactation acini, the origin of the neoplasm is traced to the normal structures, in their presence, to the supposedly abnormal ones. The logical outcome of this reasoning seems to be that the residual lactation acini are no more likely to be the starting point of the malign-

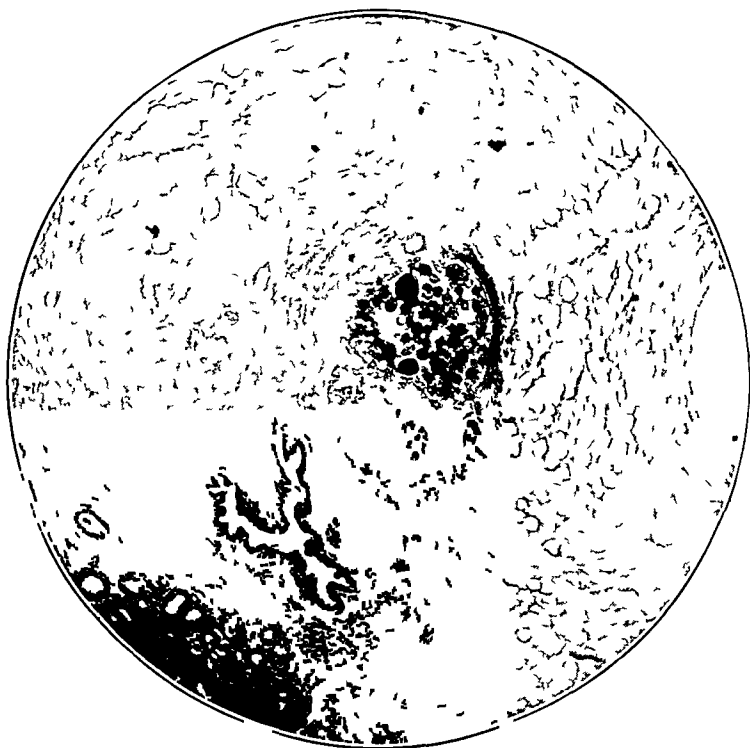


Fig 50 — These residual lactation acini, discovered in a breast removed for chronic cystic mastitis, show what may be looked upon as a possibly later and final stage of what was shown in Figure 49. The parenchyma having reached the stage of complete degeneration, the hyaline products have calcified, with the formation of numerous small calcospherites which are enclosed in a relatively clean walled pocket.

nant growth than the rest of the parenchyma, when, of course, they lose their significance and importance. They may, however, effect a close relationship between the growth of the cancer and the parenchyma of the gland in that they provide spaces into which the cancer easily infiltrates. Their decadent tissue may yield more readily to the invasion than the more normal structures, and the spaces they form may afford easy opportunity for the accumulation of cancer cells which mix with the preexisting cells before extinguishing and replacing them.

It seems, from all this, that the conclusion that the irregularities of involution, including the residual lactation acini, have nothing to do with the origin of cancer is justified. The suspicion arose through misunderstanding and misinterpretation of the normal process. Very pertinent in this connection is the closing paragraph of Bloodgood's paper: "When good pathologists disagree as to malignancy, the patient lives, when there is agreement, there is always a large percentage of deaths." It is not difficult to account for this state of affairs. All of the good pathologists know cancer when they see it, but few of them

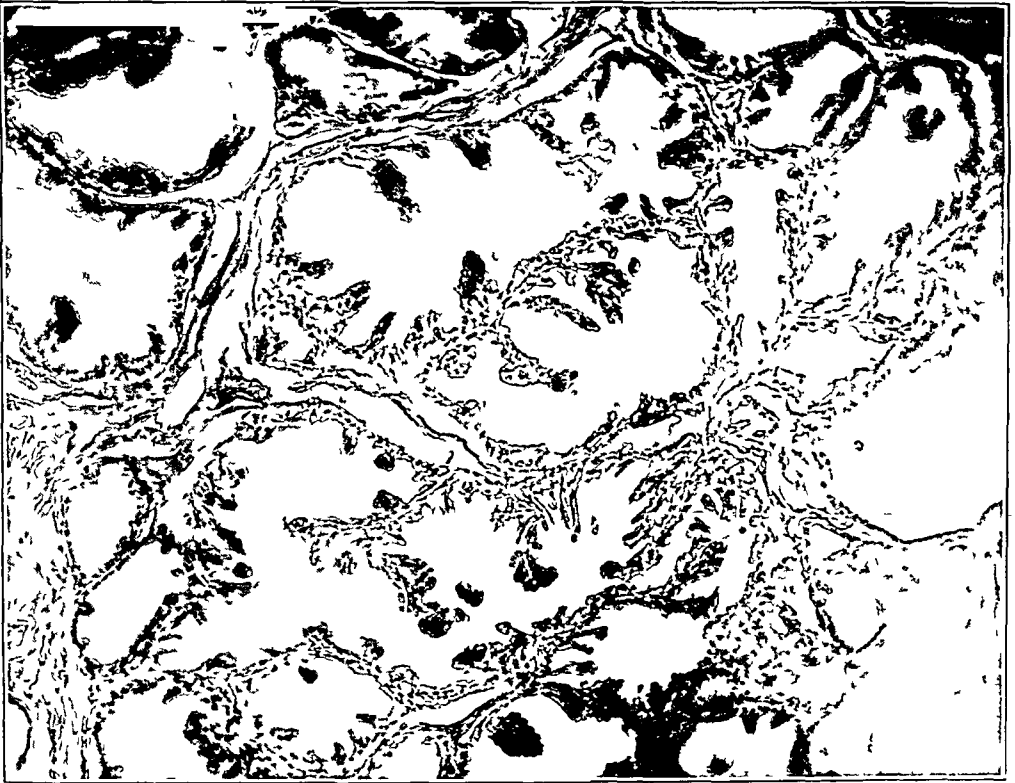


Fig 51—This breast was surgically removed and in it a very small scirrhous carcinoma was found. The patient had lactated twice, the second time sixteen years before the operation. All the modifications of involution were found, including the area of full lactation hypertrophy shown in the illustration with no other change than eosinophilia of the atrophic epithelial cells, some of which had coalesced. The stumps of interacinar septums are numerous and striking.

are sufficiently acquainted with the conditions obtaining in the normal involution of the breast to be sure that such of its peculiarities as they see for the first time are not abnormal and indicative of a malignant change. Thus they fully agree with respect to the former, and disagree about the latter.

## THE CYSTS OF THE BREAST

Cysts are like tumors in that after they attain a certain size it is no longer possible to determine from exactly what structures they arose. In the present connection it is unnecessary to consider any kinds other than those that arise through disturbance of the parenchyma of the breast. Such are extremely common and there seems to be very little objection to the general statement that they arise from very small beginnings.

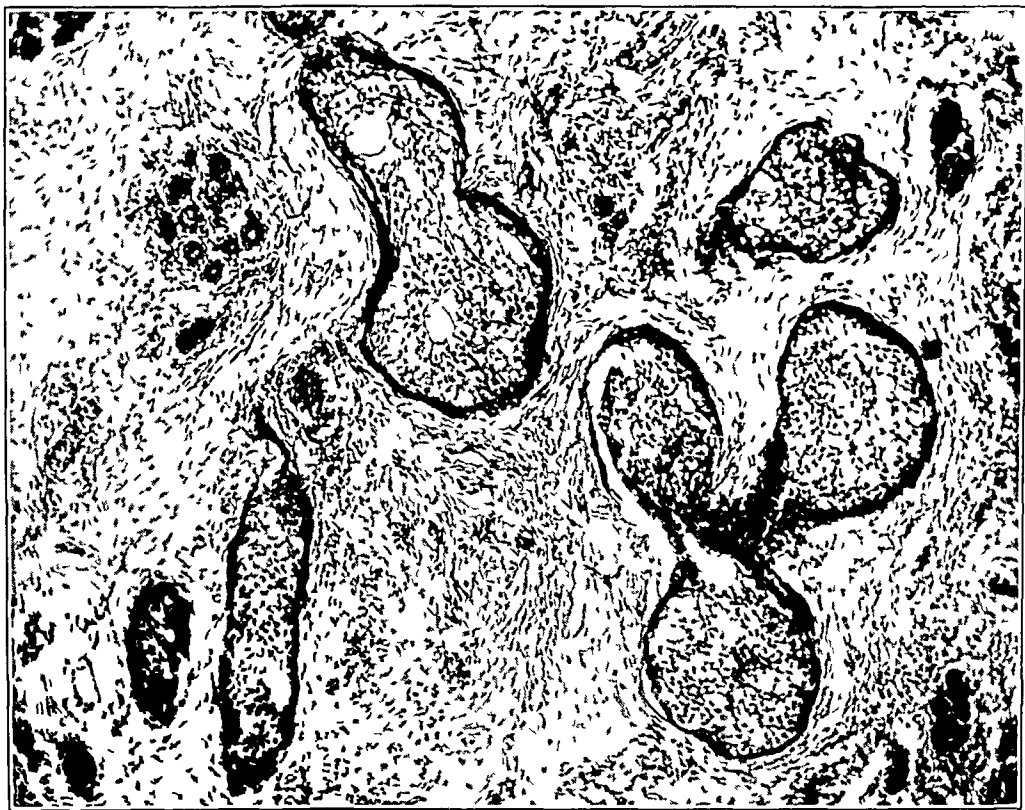


Fig 52—The area shown in the illustration, from the same breast as that shown in Figure 51, was far away from the cancer, and shows involution of several lobules, the atrophy of the interacinar partitions and slight transformation of the epithelial cells—"blasse-epithelzellen" giving the impression of dilated ducts filled with cells. The explanation of the cellular structure will become evident upon examination of the following illustrations of the same field under a higher magnification.

The examination of the material embraced in the present research suggests that there are only two sources from which they may originate, the ducts and the residual lactation acini.

In forty-nine of the 150 cases studied, the sections showed more or less rounded openings, visible to the naked eye, which microscopic examination proved to be epithelial lined spaces, for the most part

recognizable as ducts, but some of which were the residual lactation acini. In most cases they appeared empty, but some were filled with jelly. In all cases it seemed that distention was present or had been present. These were microcysts, and as such the larger cysts probably begin.

Two of the sections were from virgins (women that had not borne children), all the others were from parous women. In only two cases were there cysts having a diameter of more than 0.5 cm. This does not signify that this is the proportion of the larger cysts among normal

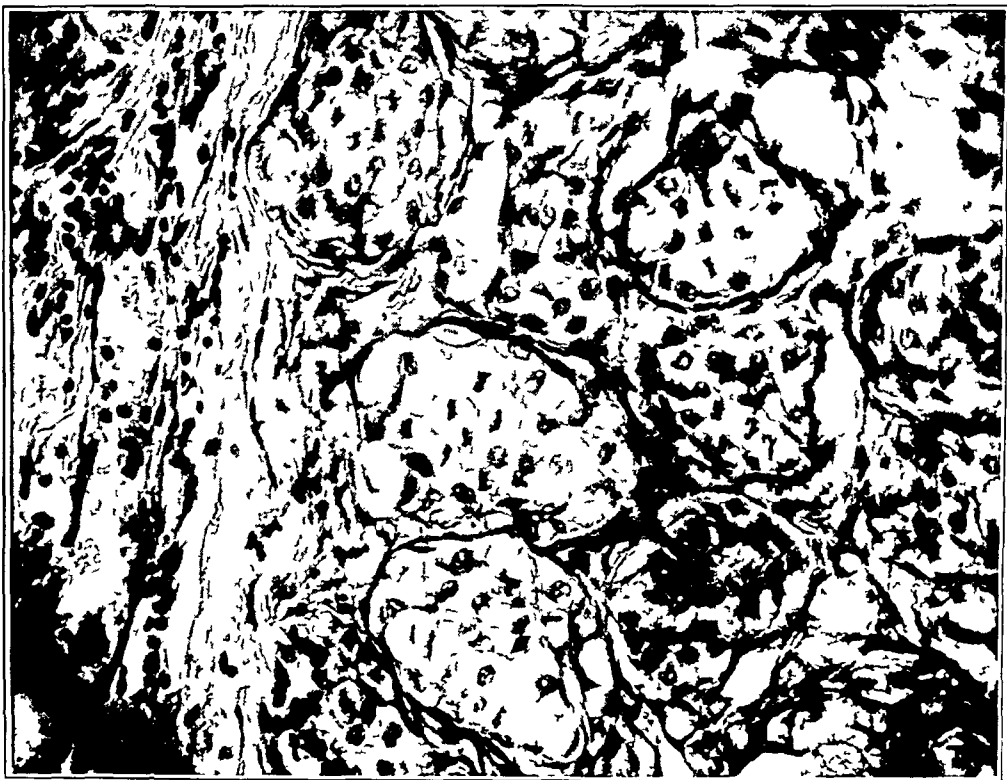


Fig. 53—The “blasse-epithelzellen” now appear as transformed and atrophic cells of the acini of the mammary lobule, the framework of which shows well. The deformed and flattened decadent nuclei must not be mistaken for mitotic figures. The cause of the swelling and pallor of the cells is not known.

breasts, but that cases containing cysts were avoided by those collecting the material, as it was especially stipulated that only normal breasts were desired, and naturally breasts containing cysts were regarded as abnormal. The only usefulness of the material collected, as far as the study of cysts is concerned, is an opportunity to discover the probable sources of cyst formation.

Cyst formation is referable to secretion or exudation associated with retention from obstruction. If the obstruction is complete the amount

of secretion or exudation necessary to form a cyst need be very small, if incomplete, it must be larger in proportion to the opportunity for outflow, in order that it can accumulate. Cysts resulting from complete obstruction must be but slightly variable, growing larger as fluid is added to their contents, smaller if it is absorbed, or remaining unchanged if neither condition occurs. Cysts following incomplete obstruction may vary considerably according to the additions and subtractions that may occur in their contents.

The secretory function of the breast is not confined to the cells of its acini, but is shared by those of its ducts. It has already been shown that the first activity of the breast, the secretion of the "witch's milk"

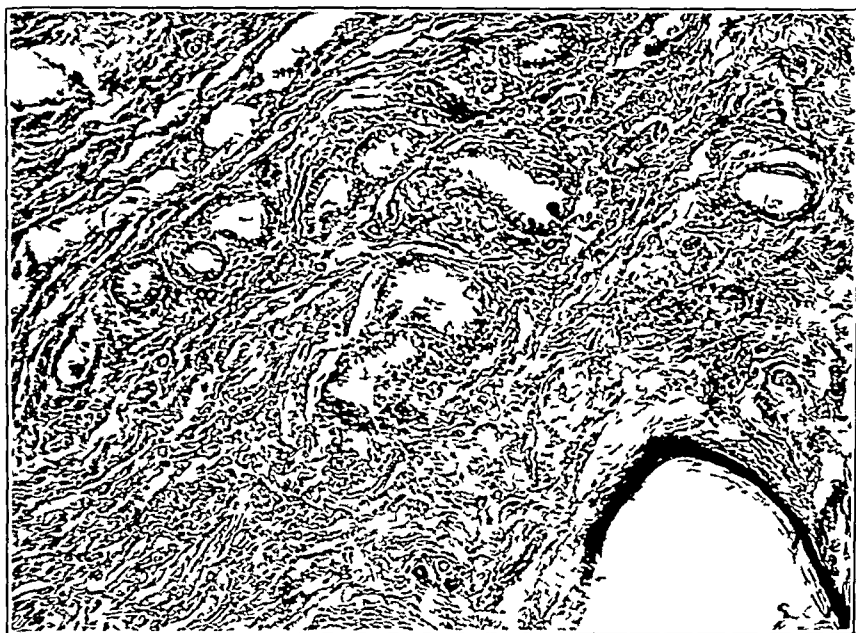


Fig 54—Mammary gland of a bitch that had had pups. It shows typical residual lactation acini, the epithelial cells of the larger having the typical eosinophilic cells, which, of course, cannot be shown in the illustration.

takes place from the ducts, as does the occasional serous secretion of the breasts of men, and of virgins at the menstrual periods. In the breast of the parous woman, in the intervals between pregnancy, and perhaps after the menopause, some secretion may also occur from this source, under certain conditions.

The cysts that follow involution—those of chronic cystic mastitis—usually contain clear serous fluid, and most of the distention takes place in the ducts. It may, therefore, be concluded that they arise rather from exudation than from secretion, and that the acini and milk secretion have nothing to do with them. But the involution process has everything to do with them, for it leads to the collection of varying quanti-

ties of debris of various kinds, in the ducts, occasioning partial obstruction by material that cannot be washed out by the fluid, but must be retained until its own retrogressive changes transform it to an extent permitting absorption. In the meantime, the transformation products may be the source of exudation, and their affinity for water the cause of accumulation.

Visible evidence of this can be found in almost every breast after lactation. Many of the ducts contain cylindric gelatinous formations like the tube-casts common in the kidney in certain diseases. In others there are cylinders containing an admixture of what appear to be colostrum corpuscles, in still others collections of fatty granules. Occasional ductlike spaces are found to be filled solidly with peculiar-appearing pale cells, the "Blasse-epithelzellen" of Borst and Wohlsecker. These have excited considerable interest from time to time, and various speculations have been indulged in, in an attempt to account for them. Nearly all pathologists seem to conclude with the assumption that they are evidences of proliferative activity on the part of the epithelial cells, and are indicative of impending malignant change.

This seems to be a misinterpretation. Such appearances when present in the normal sections seemed not to arise through the proliferation of cells within ducts, but through the decadence of cells of acini in process of involution. In those cases in which involution proceeds without any increase in the periductal tissue, and the partitions between the neighboring acini fail to recover from the attenuation depending on the extension to which they are subjected during the full lactation hypertrophy, the epithelial cells, not being crowded and condensed by the retraction of the interacinar partitions, nor through the proliferation of the periductal tissue, seem sometimes to enlarge and become pale. The substance of an entire lobule becomes a pale mass surrounded by the interlobular tissue against which it seems to abut with a definite outline. The impression is easily mistaken for a duct filled with epithelial cells. In reality it is a lobule surrounded by perilobular tissue. A close examination with a high power lens will frequently show the structure to be composed of groups of cells corresponding to acini, the central lumen of which is no longer visible because of the enlargement and altered character of the cells.

The seminecrotic remnants of the centrally situated cells of the residual lactation acini, together with the remnants of the intermediate partitions, frequently form considerable accumulations in their spaces and may be followed by cystic distention just as in the ducts.

An examination of many breasts shows these appearances following involution: (1) occasional pin-head sized cysts, (2) numerous pin-head sized cysts scattered throughout the breast, (3) pin-head sized cysts collected in groups in some part of the breast, (4) pea or marble

sized cysts occurring according to one of the above described plans of distribution, (5) cysts similar to those described above in size and distribution, but filled with darker fluid, some reddish, some chocolate, (6) single or divided cysts as large as hen's eggs, usually filled with clear serous fluid

It seems to be the cysts that are the chief factors in calling the attention of the patient to the fact that there is something unusual about the breast. And it is easy to understand that this is probably the result of the pressure exerted by the cyst in its growth. The degree of sensory disturbance may well be in proportion to the composition of the stroma of the organ. If it is largely fatty, or if there are large quantities of the mucinoid tissue, the pressure may scarcely be felt, but if it is more fibrillar, and, therefore, less distensible, the enlarging cyst may call attention to itself through sensitiveness or pain.

The induration of the tissue adjacent to the cysts can easily be accounted for by the compression and condensation of the surrounding stroma. The occurrence of the cysts in certain quadrants of the breast can be explained on the assumption that those portions did not drain so well as others, so that contents were retained with the unfavorable consequences, retardation of involution and the formation of residual lactation acini, etc.

The cysts are of no significance in the occurrence of malignant change. It is true that occasional cysts are found, in the wall of which a cancer is situated, but this is to be looked on as an accident of association. The cyst and the cancer were both there, growing side by side, and as each enlarged, the cancer came eventually to trespass on the wall of the cyst. The relation is the same as that of cancer to residual lactation acini.

#### CONCLUSIONS

1 The breasts of young virgins are composed of a stroma of pure fibrillar tissue which shows an increasing mucinoid transformation with increase of years. Into the stroma, adipose tissue begins to find its way toward middle life, increasing until in old age the stroma is largely fatty. The parenchyma of the virgin breast always contains many canellated ducts. It may be without lobules, may contain only rudimentary lobules, or may contain well developed lobules in rare cases.

2 The mammary lobule develops in response to stimuli that may be either local or general. Pregnancy is its chief source, and it seems to be only under its influence that full lactation hypertrophy is reached. The lobules arise through budding from the ducts as determined by the stimuli. At any stage of development, the disappearance of the stimulus is followed by retrogression or involution of the lobule, whether throughout the breast or locally.

3 The lobules constituting the parenchyma of the breast in different pregnancies are not necessarily the same. There is some reason to suppose that for each pregnancy there is a different crop of lobules.

4 Involution the atrophy of the no longer needed lobules is a complicated process whose details vary in different individuals in the different breasts of the same individual and in different parts of the same breast according to local and general conditions.

5 One of the most important sources of the modification of involution is retention of secretion. Its effect is in proportion to its extent and distribution, and is without regularity.

6 Its most striking result is the appearance of residual lactation acini.

7 Residual lactation acini are harmless decadent structures having no significance in respect to the subsequent appearance of malignant disease.

8 The accumulated cellular and amorphous debris resulting from involution sometimes obstructs the outlets of the ducts and acini leading to retention of secretion and exudation of fluid with cyst formation. The cysts may result from dilatation of either the ducts or the residual lactation acini.

9 The cysts may be of a size varying from that of a pin-head to a hen's egg and may be single or multiple, uniformly disseminated, or collected in groups. They usually have smooth walls and clear serous contents.

10 The pressure exerted on the surrounding tissue by the growing cyst gives rise to sensory disturbances that vary in intensity according to the firmness or softness of the stroma. In a breast with stroma largely mucinoid or adipose, they may occasion no symptoms.

11 The cysts are benign and harmless. If they become large their excision may be indicated to make the patient more comfortable.

12 Cancer cysts are not specific entities. They are the result of the accidental coexistence of cysts and cancer in the same breast. Original contiguity followed by increase in the size of each determines final continuity.

13 The so-called chronic cystic mastitis is not inflammatory, and is not a pathologic entity. It is nothing but a result—or at most—a perversion of involution.

14 It would therefore be desirable to abandon the term and call the condition 'cystic disturbance of the breast' or if it seems better to retain one of the older designations that of Warren—"abnormal involution"—is probably least objectionable. The only difficulty lies in clearly defining when the process of involution can be said to become abnormal when it is so diversified.



15 The term "adenoma" should be used only when speaking of the encapsulated tumors of the breast. Parenchymatous increases of unencapsulated or diffused form are hypertrophies and not related to tumors.

16 There is no "cyst adenoma" of Schimmelbusch. The term is objectionable because it makes it appear as though a tumor existed where no tumor is. The appearance on which the name depends is that result of involution to which the name residual lactation acini has here been given, and which can easily be found in one fourth of all breasts that have lactated.

# THE PROPER TREATMENT OF CHRONIC MALIGN DISEASES OF THE SUPERFICIAL LYMPH GLANDS

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MILWAUKEE

The term "malign" is here used to define any granulomatous or neoplastic disease against which an individual is unable to muster sufficient spontaneous resistance to induce recovery. Consequently, unchecked malign processes lead to increasing disability and to death, and adequate checking of the disease process is a prerequisite in effective treatment. The degree of malignancy, which determines therapeutic measures, varies with the disease, with the individual, and with the stage of the process, and is, consequently, to be measured in each instance by the preponderance of virulence over individual resistance at the time of observation rather than by pathologic nomenclature.

Chronic malign diseases of lymph glands are of three varieties: (1) granulomas, for example, tuberculosis, (2) neoplasms, especially carcinomas, and (3) a group of maladies intermediate between granulomas and neoplasms, which includes Hodgkin's disease, lymphocytic leukemia, lymphosarcoma, chloroma, and the so-called primary endothelioma and spindle cell sarcoma of lymph glands. All are due to prolonged irritation which is usually traceable to lesions of the skin or the mucous membrane or their appendages.

The primary surface lesion in tuberculosis may be a well marked ulcer, an evanescent dermatitis or catarrhal inflammation, or a portal of entry may be so slight in extent and heal so promptly and perfectly that it is never discovered. Cancer may originate apparently as an idiopathic tumor that may or may not ulcerate, or it may develop in epithelium long affected by benign ulcerations, inflammatory hyperplasia or involution metamorphoses. The nature of the epithelial lesions which constitute the portals of entry in diseases of the Hodgkin type is not known. Some irritation of epithelial surfaces has long been recognized as a precursor of the malady, though no definite or characteristic reactions have been described.

The provocative irritants are products of bacteria or of morbid cells or of both morbid cells and bacteria and exhibit predilection for hematopoietic tissues. The lymph glands particularly are at first the more obviously involved, but the bone marrow is also affected and ultimately those general reactions called cachexia are produced. The modes of offense of these diseases are similar; the resultant defensive responses are categorically identical and the fatal issues are produced in the same

manner The term "malignant disease" is, therefore, better used to define a deficient biologic reaction against certain irritants than as a synonym for cancer For example, tuberculous adenitis may be more malignant in one individual than carcinomatous adenitis is in another, or cancer may exceed Hodgkin's disease in malignancy In other words, there is a group of diseases, etiologically and histopathologically distinct, yet pathogenetically similar, that possess unequally the same malign potentiality and are controllable so long as the powers of defense are preponderant

Histologic peculiarities that identify the type of any of these diseases will be disregarded as less significant for present purposes, and consideration will be given to general characteristics of greater practical importance

Malign diseases exhibit two chief methods of attack The more rapid or acute form possesses the vice of becoming more promptly uncontrollable and the virtues of manifesting itself early and of provoking more active defensive responses The more insidious, chronic form, often originating in less obvious initial lesions, is prone to have achieved a lethal dissemination before it is recognized, because defensive capacity has been gradually destroyed without having been stimulated to the compensatory overactivity essential to recovery There are infinite gradations between the extremely acute and chronic forms, but the striking examples which emphasize the controlling power of defense are the transitions between the two, especially the explosive and rapidly fatal disseminations so often seen late in the chronic varieties

Extension from a primary lesion or from secondary foci so often skips contiguous gland groups to involve those that are more remote that any group of enlarged glands may neither indicate the location of the initial lesion nor mark the frontier of disease Glandular enlargement—lymphoma—although it is the commonest characteristic of malign diseases, is undependable for diagnosis because malign and benign lymphomas may co-exist Nor is the evidence obtained from histologic examinations of lymph glands entirely reliable A disease may be regressive to the extent of approaching latency and this fact may escape detection pathologically, or it may be present in a gland under conditions that assure progression and be histologically unrecognizable

The most dependable evidence of relative malignancy is the type and extent of the periadenitis which frequently also measures defensive responses It matters not whether the earliest lymph gland involvement is a carcinomatous metastasis or whether the latest involvement is a neoplastic metamorphosis of a primary granuloma, the intraglandular response is a form of subacute or chronic adenitis The same irritation

that primarily induces adenitis continues and extends to cause periadenitis. Periadenitis is primarily a nonspecific inflammatory process subject to exacerbations during the recurrent periods of more active progress of the disease. In addition to causing thickening of gland capsules, it is destined ultimately to form cicatrizing adhesions between adjacent

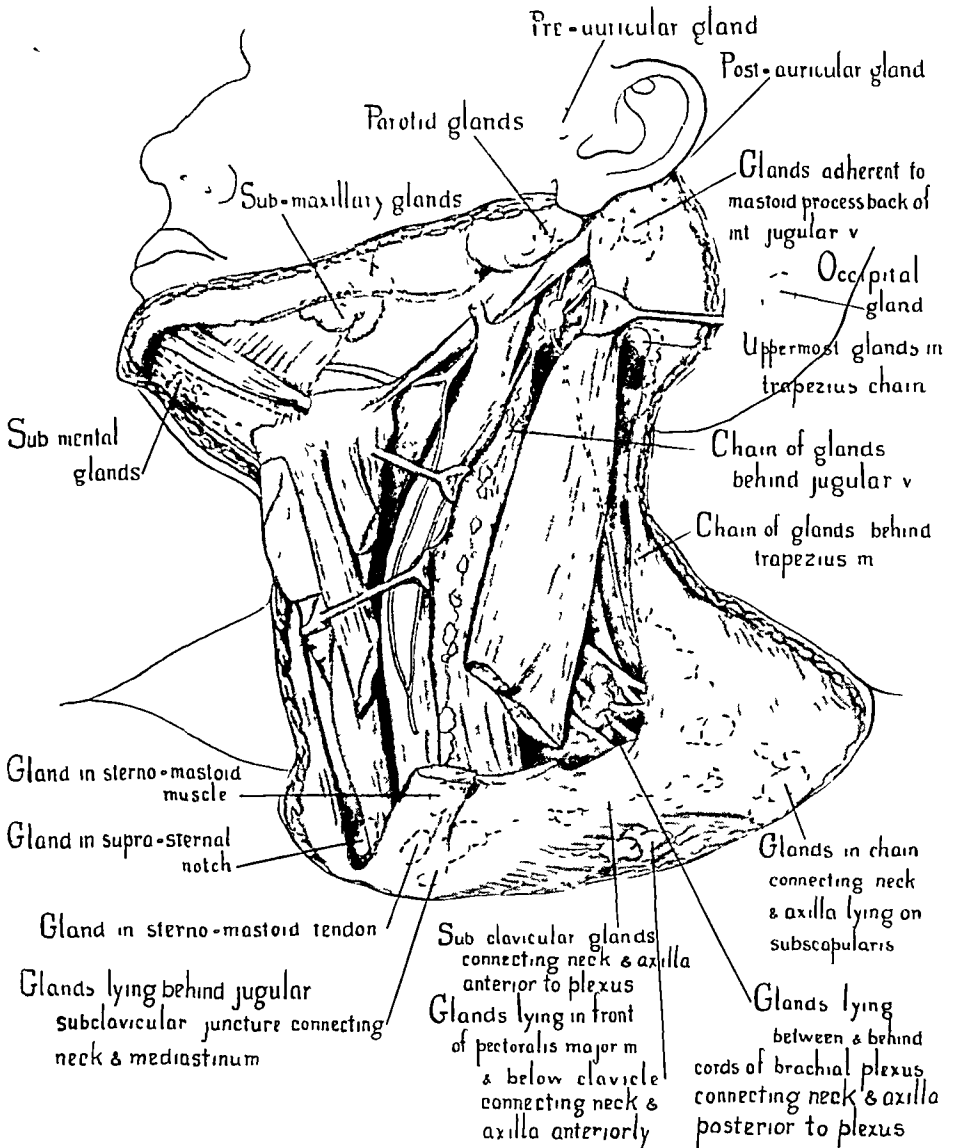


Fig 1—Skin removed to show location of glands that determine the boundaries of tissue that must be excised if the operation is complete

glands and surrounding structures. If the malady is extremely malignant, the intraglandular morbid tissue may grow through the capsule and intensify the periadenitis by invading the extraglandular adherent structures or this specific outgrowth may proceed in the absence of periadenitis, if defensive powers have been dissipated or if they have

been deficient from the onset. The nature and extent of periadenitis are indicative of disproportions between existing powers of offense and of defense and do not, even when signally invasive, identify a malignant neoplasm, since this occurs in tuberculous adenitis. Absence of periadenitis is noteworthy if there is extreme chronicity, as it then marks an irritation that has been too insidious to cause response.

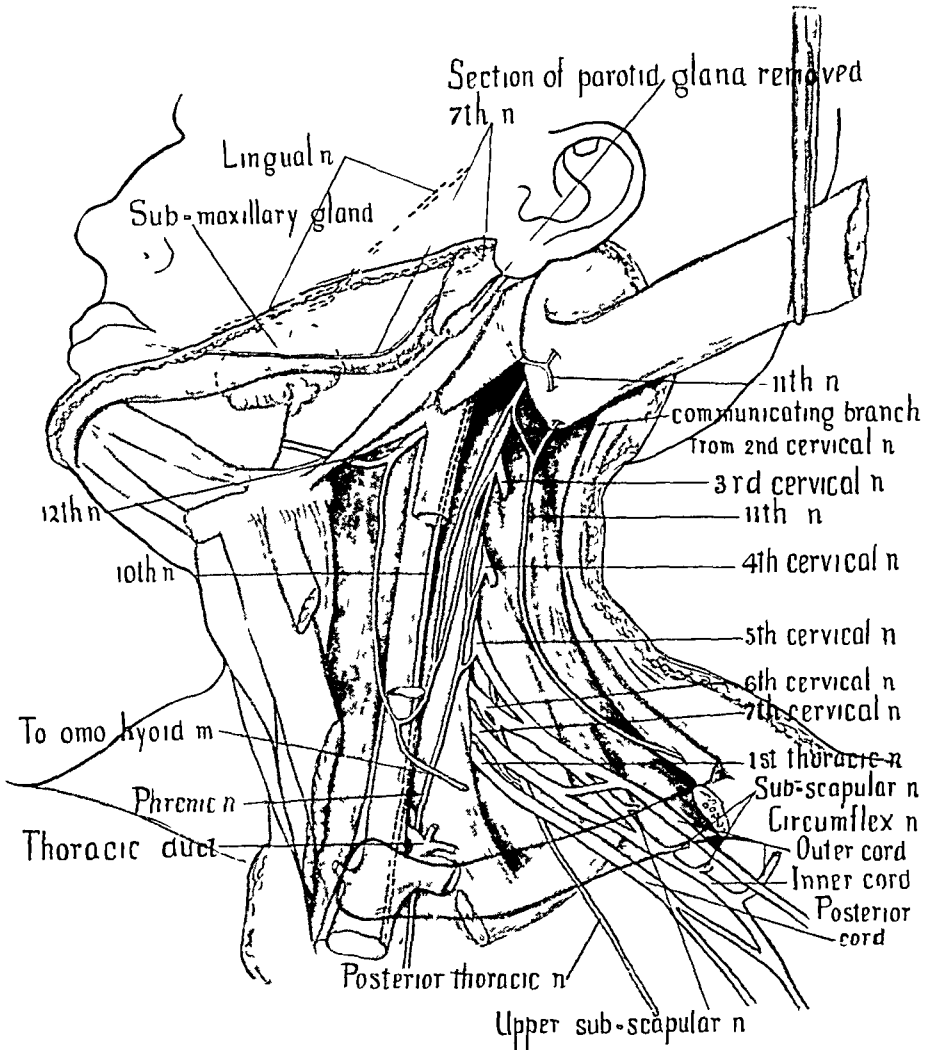


Fig 2—Skin and muscles removed to show the nerves and vessels that must be spared in dissection

Differential diagnosis between malign diseases is usually simple and is of less moment than a recognition of existing or of potential malignancy. An estimation of malignancy resolves itself into a study of local and general responses. Rapidity of dissemination, the nature of the involvement and the impairment of function in the region or regions involved are more significant than the size of lymphomatous masses. These conditions likewise determine the probable success of

excisions because they indicate the structures that must be sacrificed. The more perfect the postoperative return of function, the greater is the prospect of permanent regional freedom from disease. Local resistance is determined by the integrity and richness of blood and lymph circulations, which in turn are largely controlled by activity. An estimation of general resistance can be fairly accurately based upon the status of the circulation and upon the blood picture. General

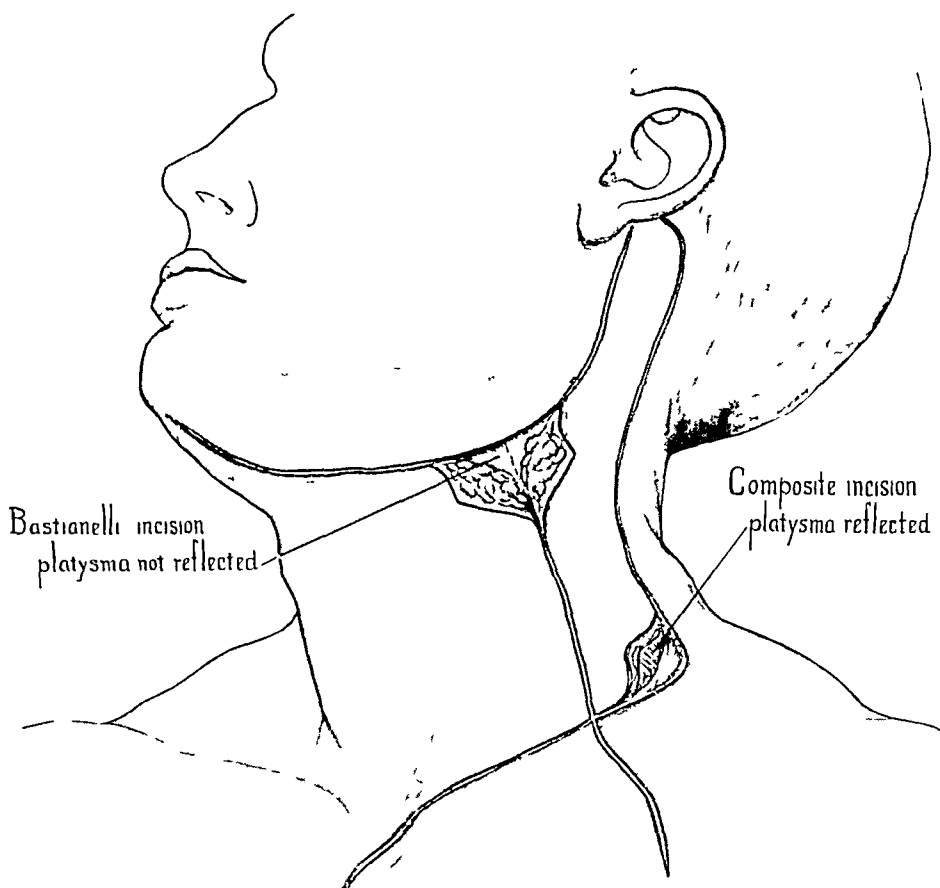


Fig 3—Skin incisions

appearance may be misleading, so it is unsafe to rely upon snap judgments. Persistent abnormalities in blood pressure responses to exertion are significant. A lymphopenia or anemia that is irresponsive to proper stimulation is evidence of a permanent loss of powers of regeneration in the mother cells and is indicative of hopelessness. A considerable reduction in the number of platelets, especially when those present are abnormally large, positively contraindicates operation.

Even the meager suggestion of the evolution of malign diseases that has been given suffices to determine methods of treatment, but,

since it is more essential to recognize what cannot be accomplished and what should not be attempted, the negative therapeutic aspect will be presented first

If "cure" defines an elimination of disease so complete as to preclude the possibility of a recurrence, then malign diseases are generally incurable. Were methods available whereby latent rests of all diseases could be detected at necropsy, with a degree of accuracy comparable to the discovery of latent tuberculosis, it would be possible to obtain accurate data to establish this contention. Nevertheless, the numerous

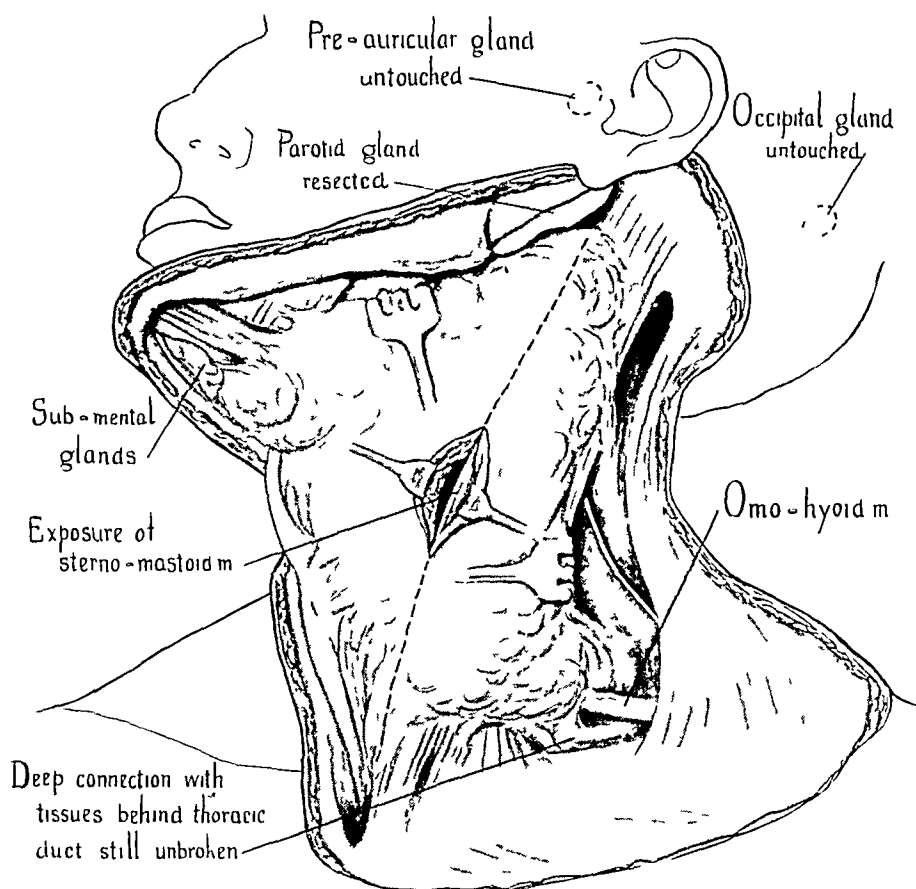


Fig 4—Concentric dissection started, spinal accessory nerve isolated, sternocleidomastoid muscle exposed anteriorly

examples of recurrences, recrudescences, reinfections, or whatever they may be called, that occur after years of apparent recovery from any of the maladies in this category give necessary supporting evidence, which is amplified by the better results obtained as treatment is improved. It is a fair presumption that virtually all that survive middle age have been subjected to conditions favorable to the starting of malign affections. The deficient individual resistance required for the diseases to become established is rarely transient. Greater safety is assured to

the patients if this biologic defect is held to be persistent, which, therefore, can never be eliminated by any means and can only be minimized by equally persistent effort

Therapeutic failures constitute the most profitable source of information if used to prevent subsequent mistakes. Death results from lymphatic involvement and the consequent local and general injuries. The commonest cause of failure after operative treatment, especially in affections of the cervical glands, is local or regional recurrences,

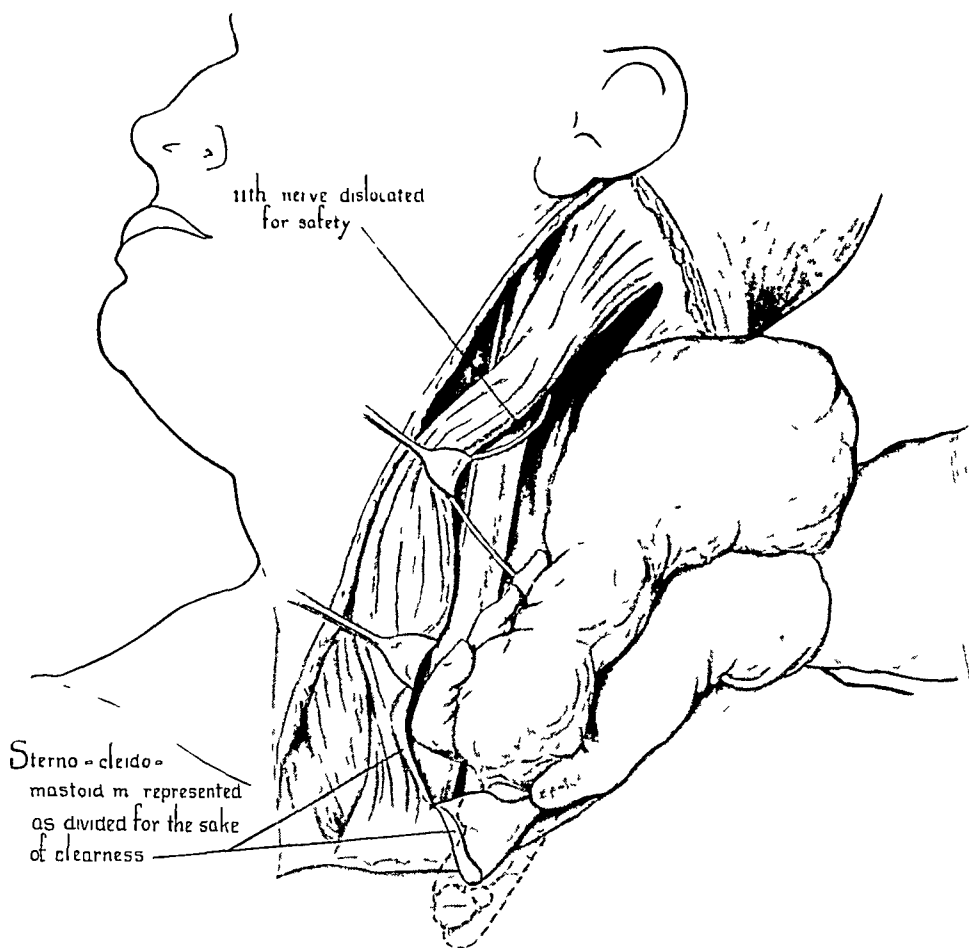


Fig 5—Dissection completed, except at the jugulosubclavian angle, to show method of dislocating the upper mediastinal tissues

which are due to incomplete removal of the initial lesion and to inadequate regional excisions. On the other hand, successes attained through illogical methods constitute the most unprofitable source of information as well as the most common source of misinformation. Statistics advanced to show the results obtained by various therapeutic methods are peculiarly unreliable because they cannot show the most important phase of the problem, namely, the degree of malignancy at the time



of treatment. Indeed, the question occasionally arises as to whether the malignancy alleged to have been present was real, potential, or purely hypothetic. Neither do these impressive percentages show the causes of failure. For instance, a given series of patients treated for cancer originating in the mucous membrane of the mouth may be cited to show that a certain proportion have remained well for certain periods, another portion are dead of the disease, and the death rate attributable to operation was a certain percentage. The failures due to local recur-

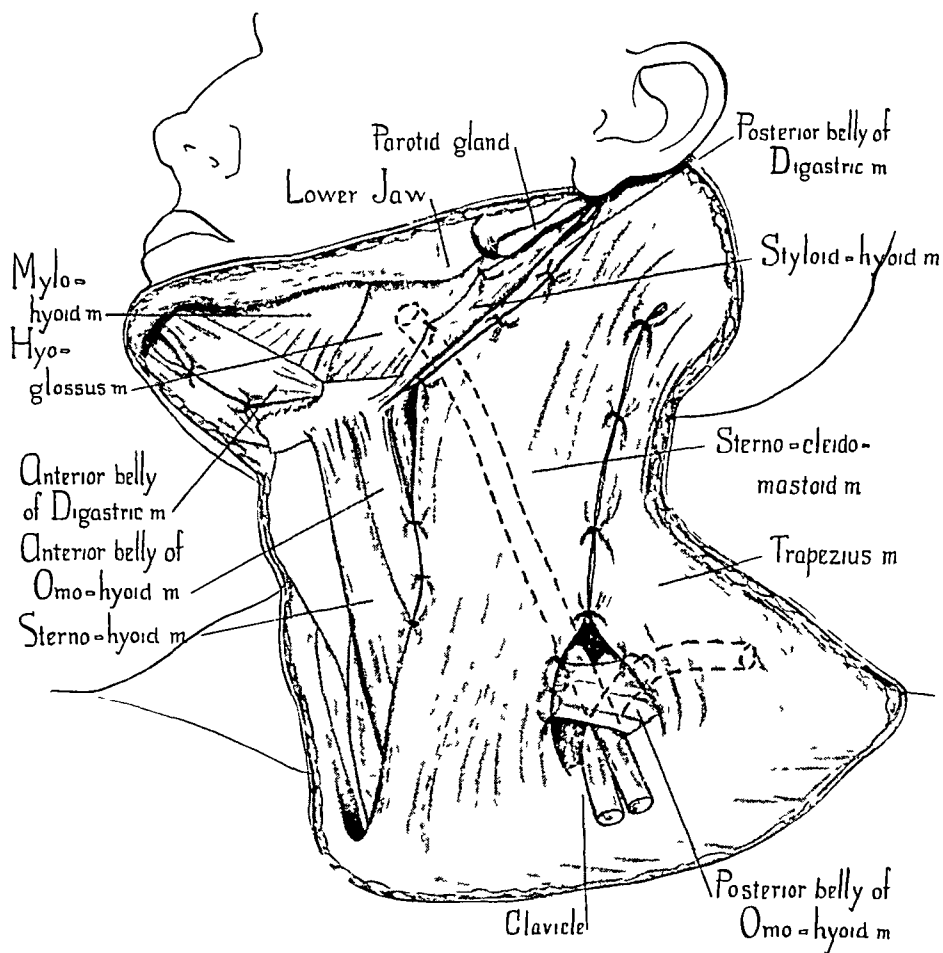


Fig 6—Muscles sutured to protect nerves and to provide surface upon which skin flaps are to rest, soft rubber drainage tubes to be removed the second day

rence, or better, local persistence, because of incomplete removal, do not all appear. However, two more important points are apparently established. Wider excisions usually attempted only when the involvement was greater and the degree of malignancy had increased have produced some lasting recoveries. The mortality due to more complete glandular extirpation is small, even when the extirpation was performed late in the disease, if it is not confounded with the death rate produced by the excision of primary lesions like those in the tongue.

True it is that recoveries occur after destruction of the primary lesion without gland excision, and the latter operations are, therefore, not always necessary. The number is smaller than is accepted and these fortunate individuals may be selected only by the aid of a time factor which also determines a larger group of unfortunates condemned by omission and procrastination. In view of the very low mortality rate following excisions of regional lymph glands, a larger proportion of lasting recoveries would be obtained were all patients subjected, as a

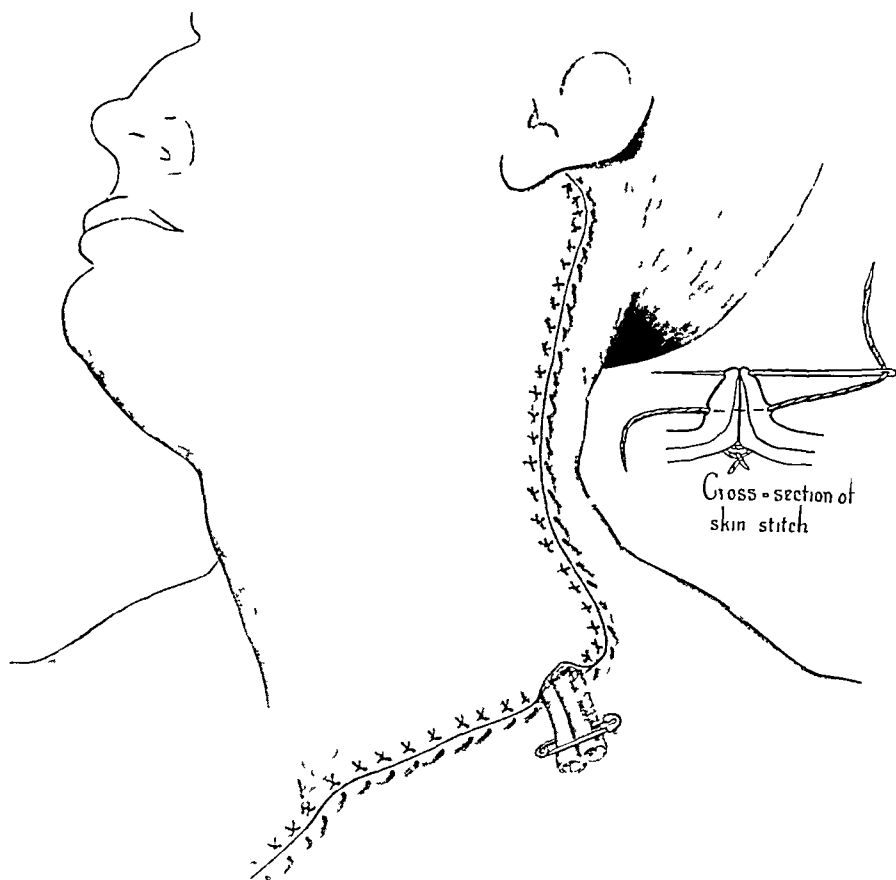


Fig 7—Closure completed, skin suture usually inserted at point where drainage tubes emerge but are not tied until the second day, small diagram shows method of inserting buried and superficial skin sutures

rule, to even incomplete extirpations, regardless of the size and duration of the initial lesion and a failure to demonstrate lymph gland involvement. Proceed one step farther and the same comparison may be made between complete and incomplete glandular excisions, as has just been made between incomplete excisions and no excision. Moreover, it is equally true that recoveries are more frequent after excisions when there has been slight glandular involvement, also that incomplete opera-

tions are more likely to be followed by local recurrences, which, in turn, are of increased malignancy and prone to produce a rapidly fatal progress of the disease. Complete operations can be performed with mortality and morbidity rates barely exceeding those due to

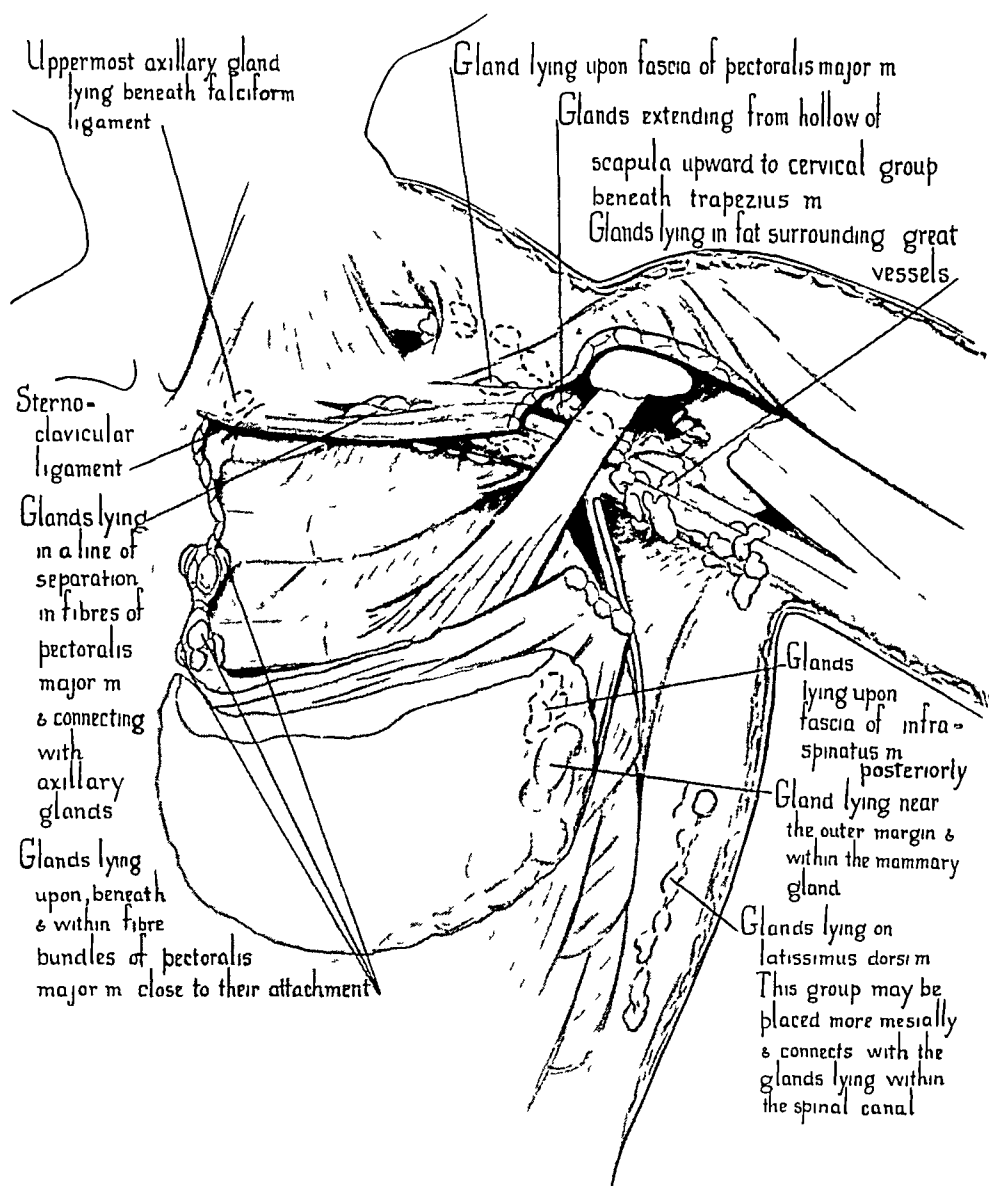


Fig 8—Diagram showing location of glands that determine the boundaries of excision

incomplete excisions and for which more than adequate compensation is found in the greater likelihood of recovery they assure. There is but one truly conservative attitude that can be taken. If operation is indicated at all, then the more favorable the conditions, the more radical should be the extirpation. If experience teaches anything, it

has taught this lesson Failure to benefit from this expensive instruction is due to the fact that partial successes masquerade so long as complete successes and so often the realization of responsibility for catastrophe is blunted by its tardiness in appearing Could deaths and the needlessly incomplete, or delayed, functional recoveries due to

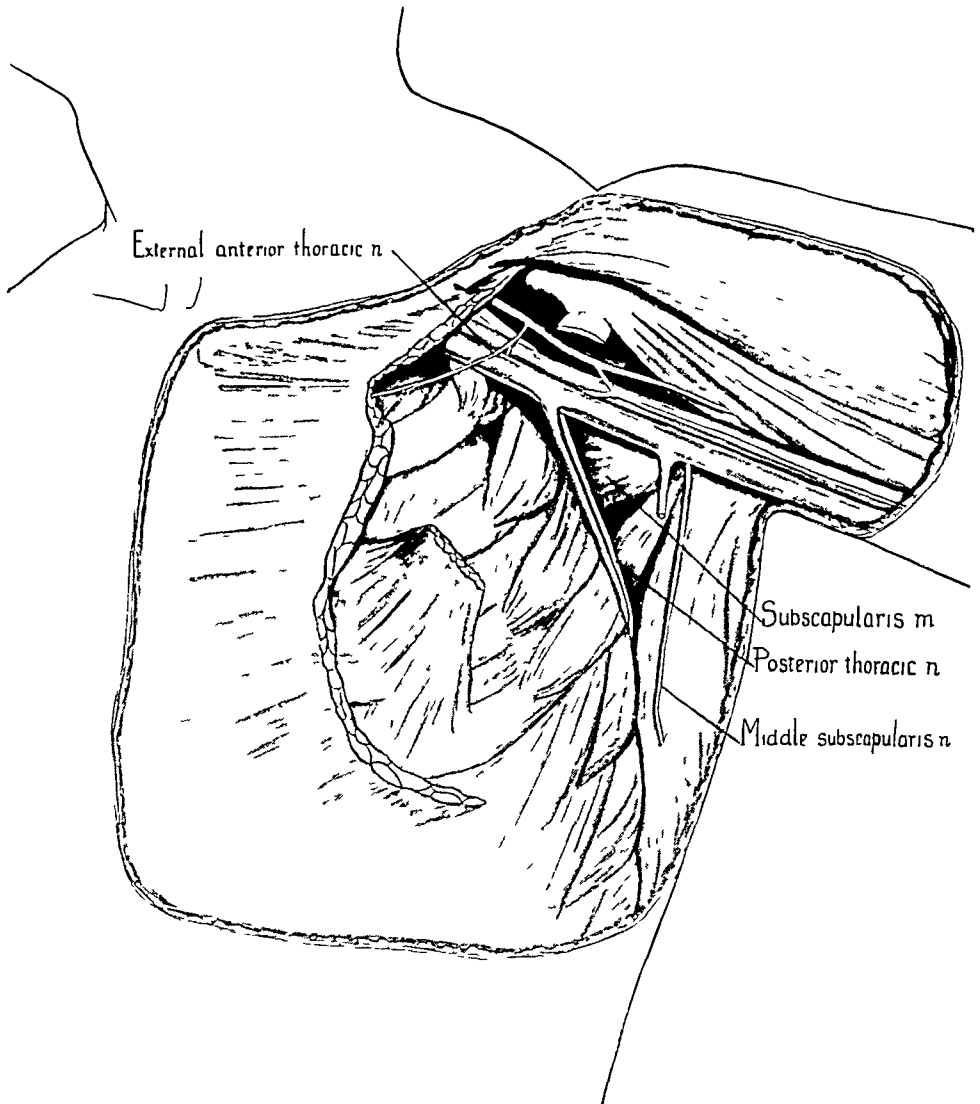


Fig 9—Diagram showing nerves and vessels to be saved in making dissection

improper operative methods occur as promptly as they do following ill-advised treatment of appendicitis, both lay and professional opinion would demand more effective treatment

Radiation is at present the means besides excision usually relied upon to destroy initial lesions and to control malign lymphomas Radium and roentgen ray can destroy primary foci of disease, but too

frequently they fail to control them, and even may stimulate the growth of the least formidable thereof, the basal cell epithelioma. Similarly, extirpations have been unreliable and dangerous in removing advanced cancer of the tongue, tonsil and antrum.

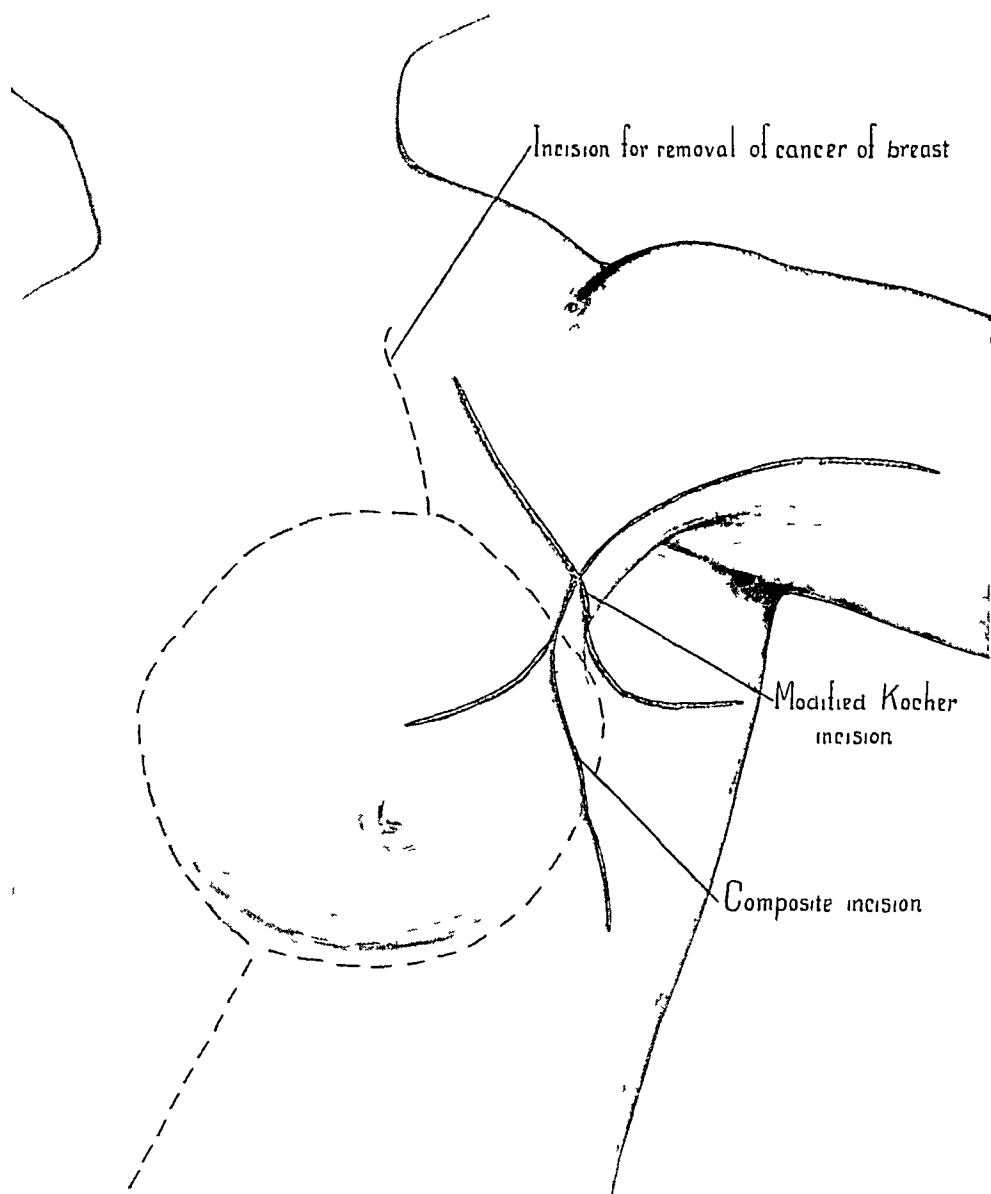


Fig 10—Skin incisions

The exposures required to control such lesions by radiation alone are prohibitively dangerous, both locally and to the blood-forming cells. Too little use is made of the actual cautery. Foci that cannot be excised may be destroyed by heat or by cauterization followed by radiation.

Proof that surface radiation can destroy intraglandular malign diseases has yet to be produced. Lymphomas usually diminish in size after proper exposures, even to the extent of becoming impalpable. The process may apparently be overcome occasionally for considerable

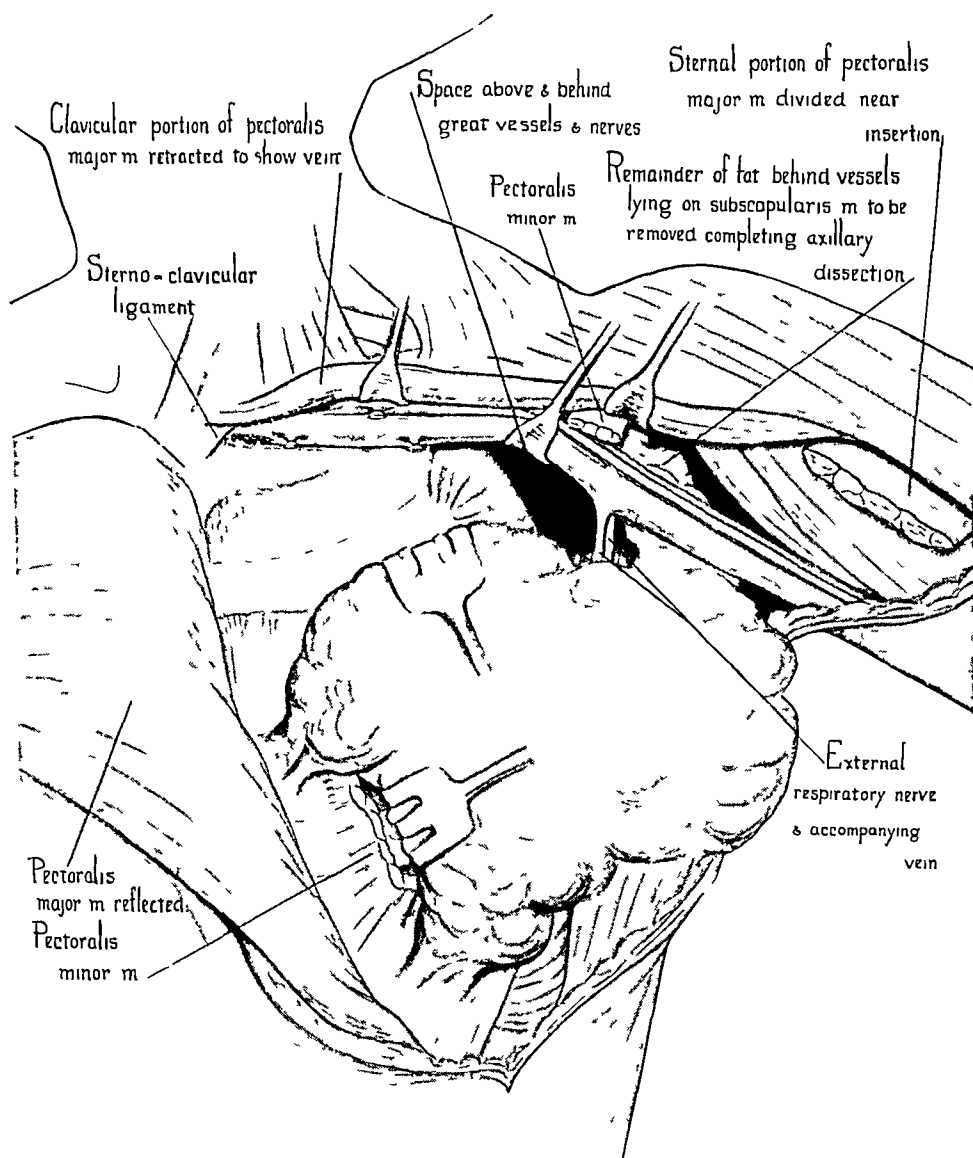


Fig 11—Sternal portion of pectoralis major muscle, divided at insertion and reflected to obtain exposure for deep dissection

periods, but eventually an uncontrollable recrudescence develops. Malign processes are modified but not destroyed. Moreover, radiation produces local and general irritation which, like that of the malign diseases it is used to combat, has a selective action upon hematopoietic tissues and ultimately is similarly destructive in its

effects Fatal lymphopenia and anemia may be produced experimentally with external radiation and may have followed and have been precipitated by its therapeutic application Facts and methods now available indicate that whenever extirpation offers at least as good

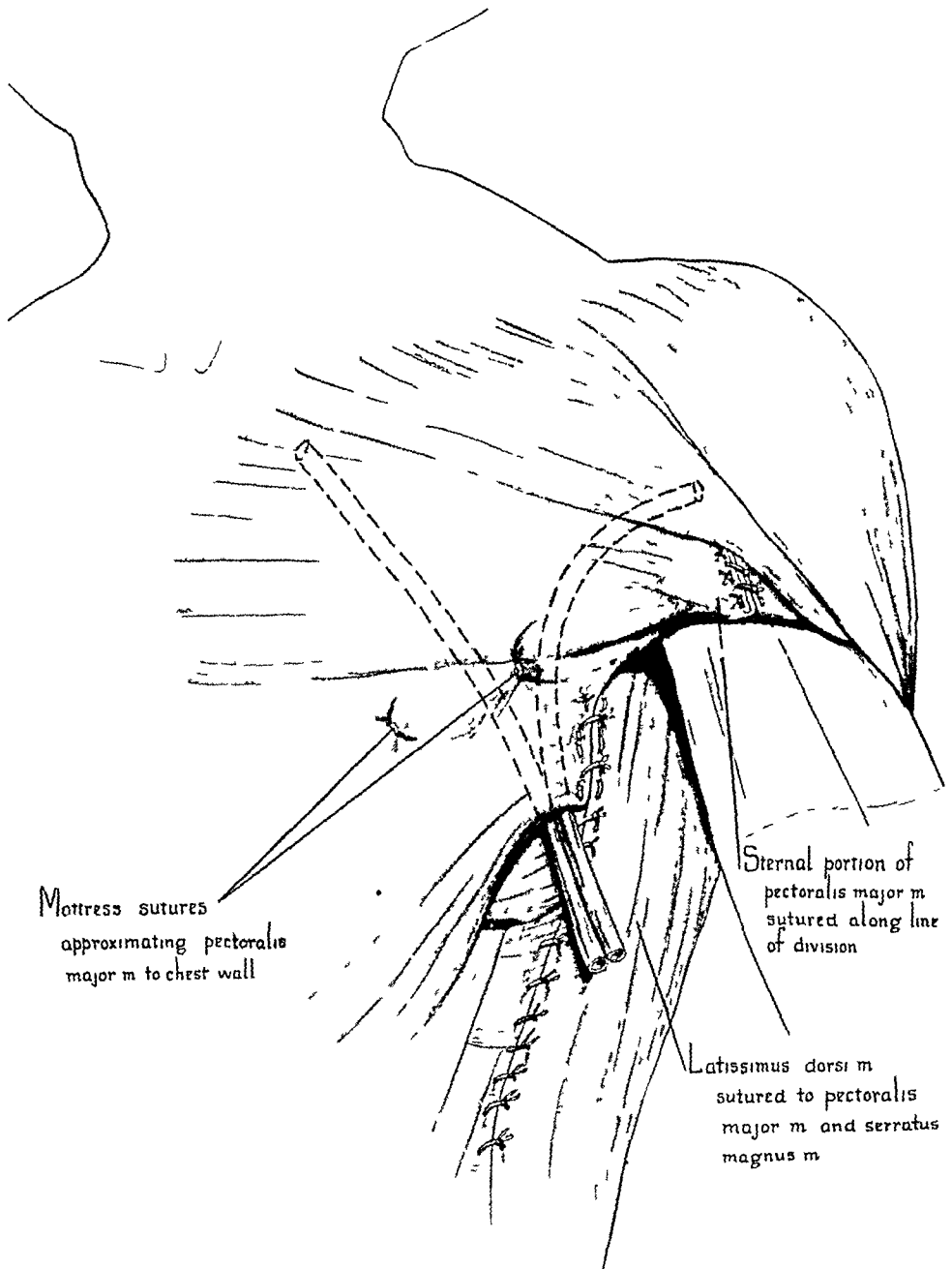


Fig 12—Method of repair when pectoralis major muscle has been saved

prospects as radiation it is more reliable and in the long run is safer Radiation used in palliation can accomplish much when operation would be worse than useless The proper combinations of operation

and radiation are yet to be established satisfactorily. One basic fact is known. Irreparable injury will follow if local and general functions are not safeguarded.

Effective extirpations of malign lymphomas from neck, axilla, and groin must remove, in addition to structures involved, all of the gland-bearing and disease-bearing tissues and those in which lie the

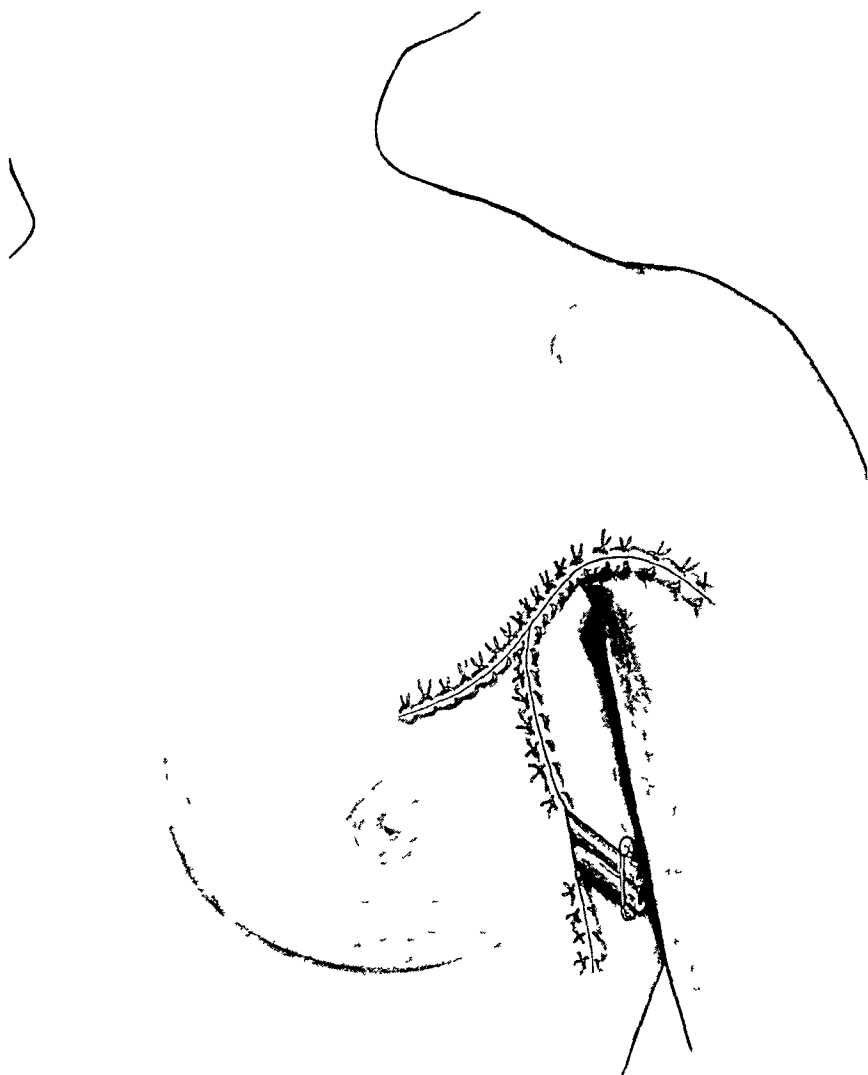


Fig. 13—Skin closure and drainage of composite incision

lymphatic connections with adjacent regions. Moreover, prompt healing and functional rehabilitation must be assured. Surgery cannot be regarded as *the* treatment of malign diseases but as *a basic phase* of treatment upon which recovery depends. The success of the surgical part of treatment is to be measured by the limits of its possibilities. To remove eradicable disease in such a manner that the regions



wherein operations have been performed are rendered permanently disease-free, to prevent extension of the disease from the area operated on and particularly extension into a body cavity, to induce compensatory hyperplasia and consequent hyperresistance in other lymphadenoid structures, and to place patients in a position that permits them to begin to exert advantageously all of their powers for recovery

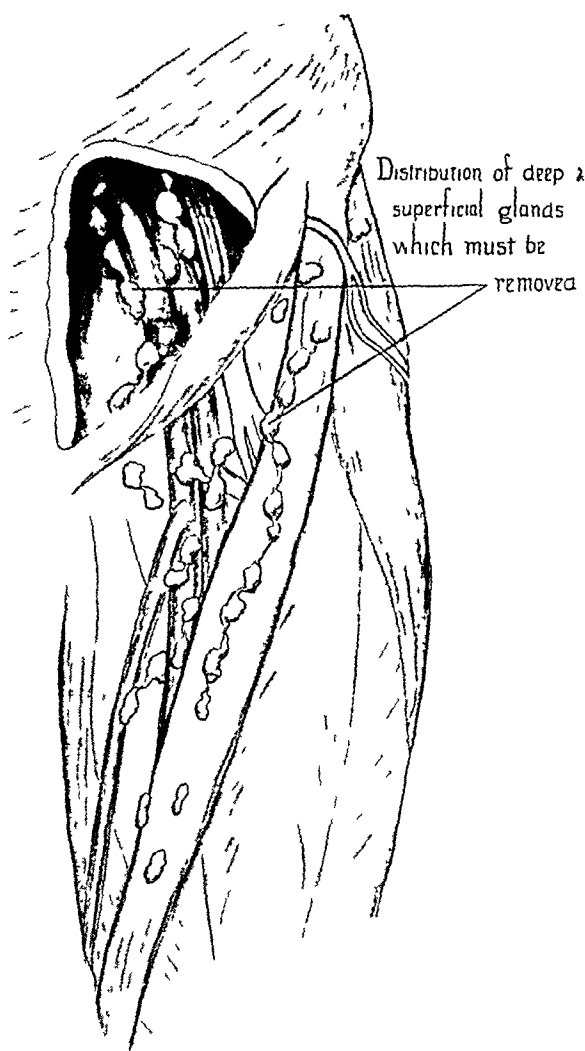


Fig 14—Location of glands that determine limits of incision

The operative methods to be described have been evolved from fifteen years' experience in treating the most malignant of lymphomas, those due to the Hodgkin's group of diseases. They have been applied also in combating carcinomatous and tuberculous adenitis wherein the problems and solutions are quite identical. Locations of dangerous glands have been determined at operation and at necropsy. Unusually

extensive excisions are advocated because less radical operations have been followed by recurrences, and the reasons for the recurrences were found to have been affected glands that could have been excised at the first operation without having added materially to the patient's burdens. Studies of tissues removed from patients suffering from cancer or tuberculosis have demonstrated that although the lymph gland involvement in these diseases is usually less general than it is

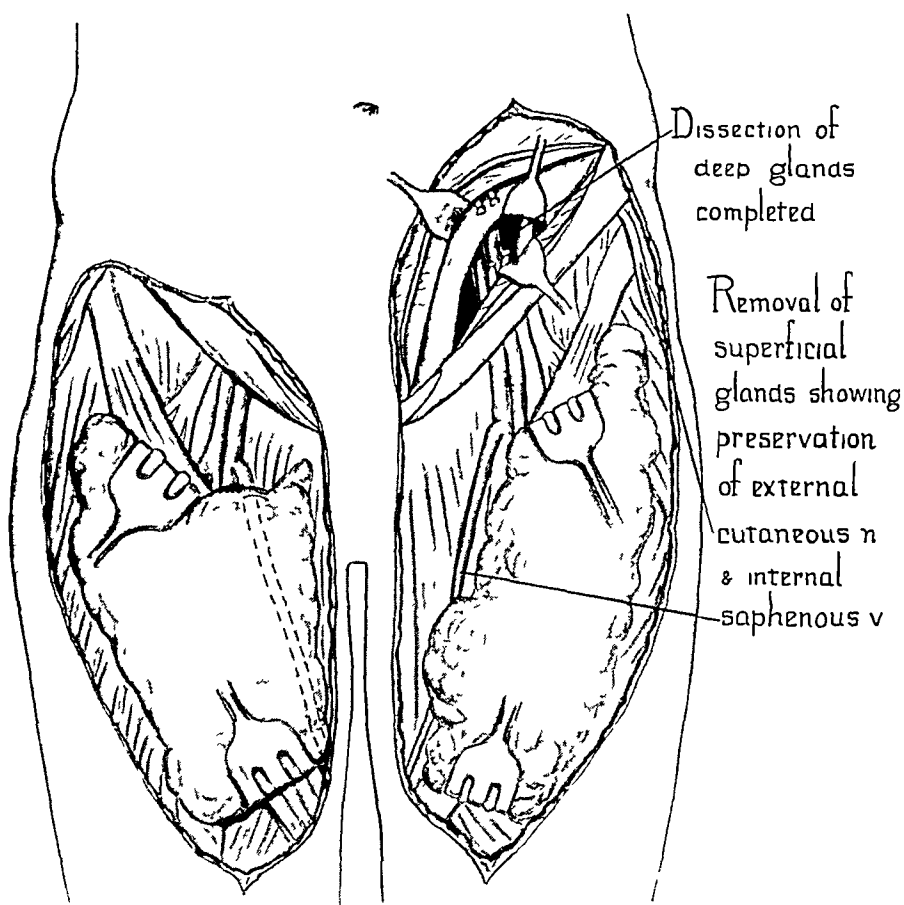


Fig 15—Dissection of superficial glands incomplete, of deep glands complete, internal saphenous vein and external cutaneous nerve spared

in the diffuse types of Hodgkin's disease or lymphocytic leukemia, nevertheless, virtually any of the glands and rarely all of the glands so affected may be invaded by tuberculosis and cancer

Regional lymph glands and vessels regenerate after extirpation if the healing is smooth, in less than three months and apparently function normally. This has been proved by characteristic responses to fortuitous acute infections. Regenerated glands are hyperresistant to the original disease since they may remain free when the involvement

has otherwise become general. Moreover, there is evidence that they contribute materially to general resistance. Successful regional resections induce lasting regressions of lymphomas in other regions and occasion at the same time notable improvement in general condition. Complete regional resections may be performed not only without detriment but with great benefit to local and general resistance. An old superstition to the contrary is still invoked to justify half-way measures.

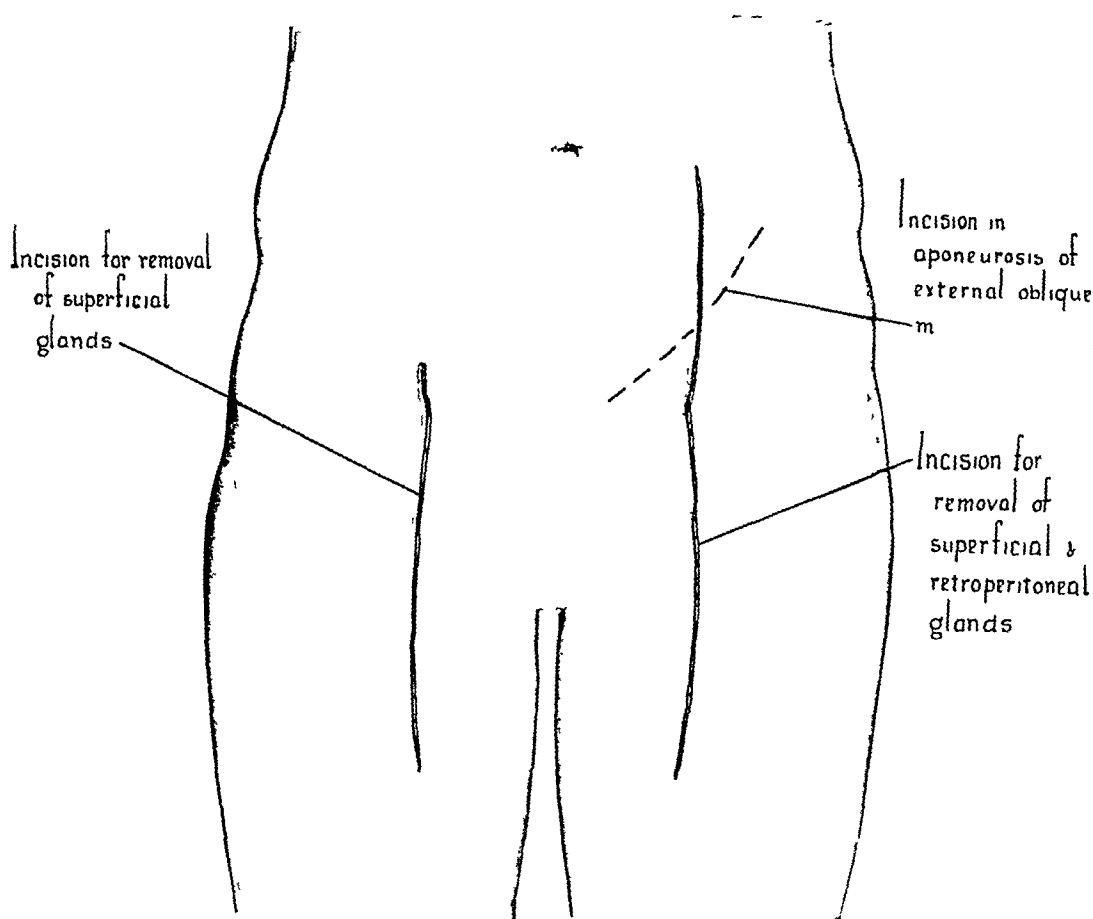


Fig 16—Skin incisions for removal of superficial inguinal glands and lower retroperitoneal glands

The mortality rate following complete regional extirpations depends upon the patient's condition. Deaths in my experience have been due to periadenitis and have occurred only in cervical operations and when landmarks were obscured and respiration embarrassed. Fatalities have been confined to patients to whom uncertain palliation alone could be offered and who accepted risks of operation to obtain the chance for relief from pain and for an extension of life that other patients, similarly affected, had secured.

Duration of postoperative convalescence is determined chiefly by infections, to which these wounds are predisposed. The affected tissues usually harbor living bacteria and the regional circulation has been impaired for a time preceding operation. If technical refinements that promote healing are not slighted, serious inflammation can be reduced to less than one in twenty-five.

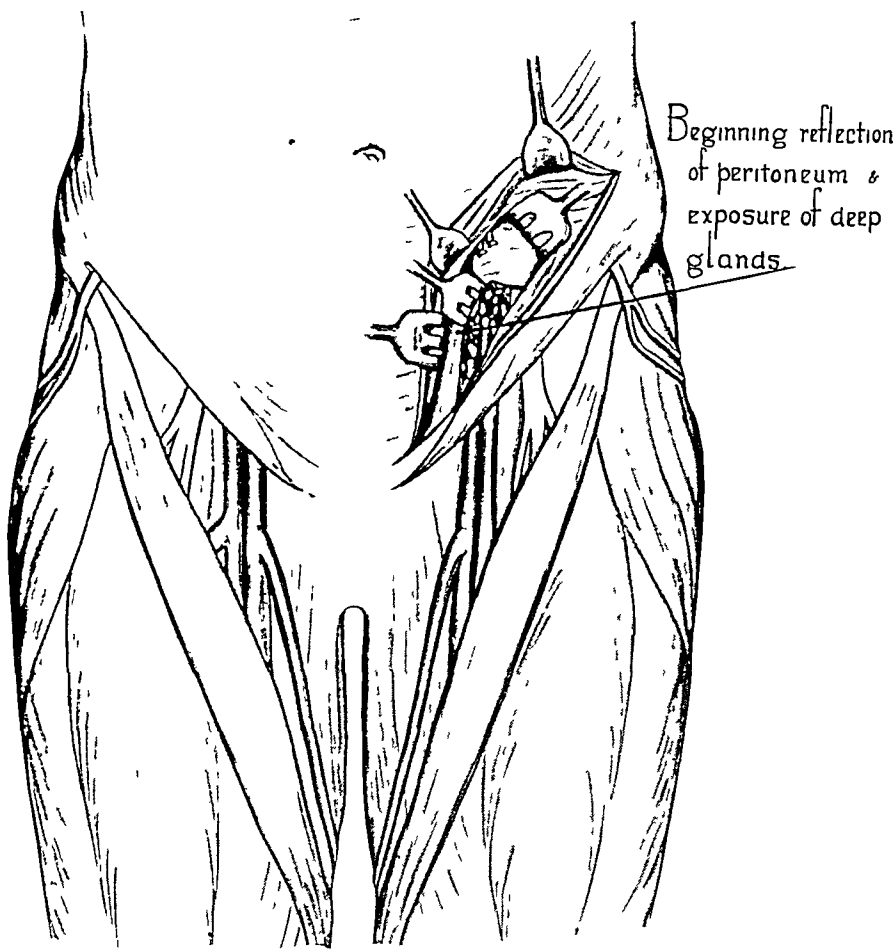


Fig. 17—Structures remaining after superficial dissection is complete, method of obtaining exposure of the retroperitoneal glands.

The following technical details are applicable to all dissections. If neglected, delayed repair and imperfect functional recovery will occur when they could have been avoided. This has held true in my own work and accounts for failures reported by other surgeons who claim they have used the methods here described.

#### TECHNIC

Skin flaps should be completely reflected as the first step, kept covered with warm moist gauze, and protected from pressure until

replaced Dissections of deep tissues should be concentric, as soon as an area is exposed, bleeding vessels should be ligated and hot moist dressings applied Sharp dissection is superior After dissection is completed, dead spaces are obliterated so far as possible by suture or tissues so fixed by suture that the pressure of bandages will lead to their obliteration A muscle floor is to be fashioned upon which the skin flaps, that have become skin grafts to a large extent shall rest and from which they are to obtain their circulation

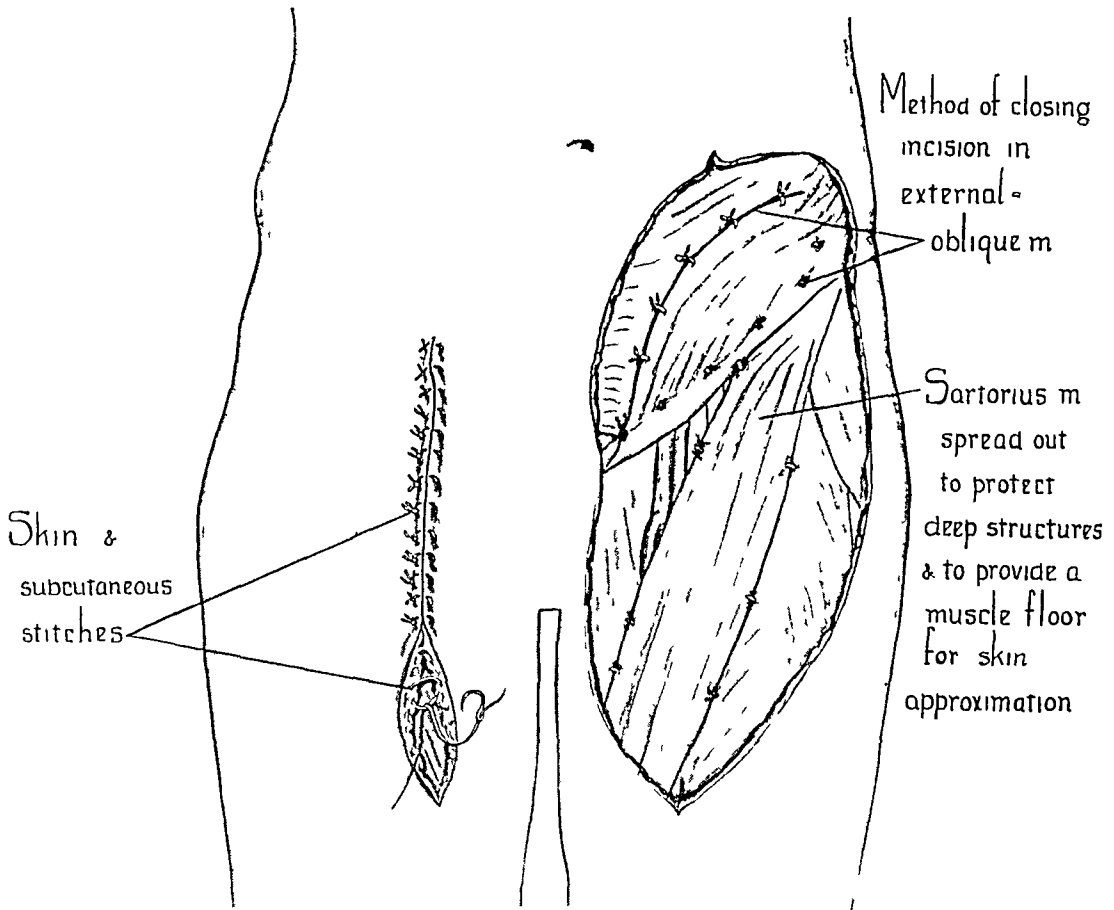


Fig 18—Deep and superficial closure, drainage of superficial wound not illustrated, no deep drainage used

The importance of constructing a floor of muscle denuded of fascia but assured of adequate circulation cannot be overestimated Halsted's<sup>1</sup> splendid contribution to this subject should be studied by every surgeon and his suggestions followed in detail Elephantiasis chirurgica is an avoidable complication with the exception of three conditions (1) that following recurrent attacks of erysipelas that occur at intervals after operation, (2) lymphedema of the external

1 Halsted, W S Bull Johns Hopkins Hosp 32 309 (Oct) 1921

genitalia following bilateral excisions of both deep and superficial inguinal glands, (3) a rare form that develops slowly a year or more after operation and is possibly due to prolonged irritation of semi-dormant bacteria that have persisted in the tissues

Attempts to disinfect the deep wound with iodine, ether, or roentgen ray are more than futile. They are harmful as they provoke greater

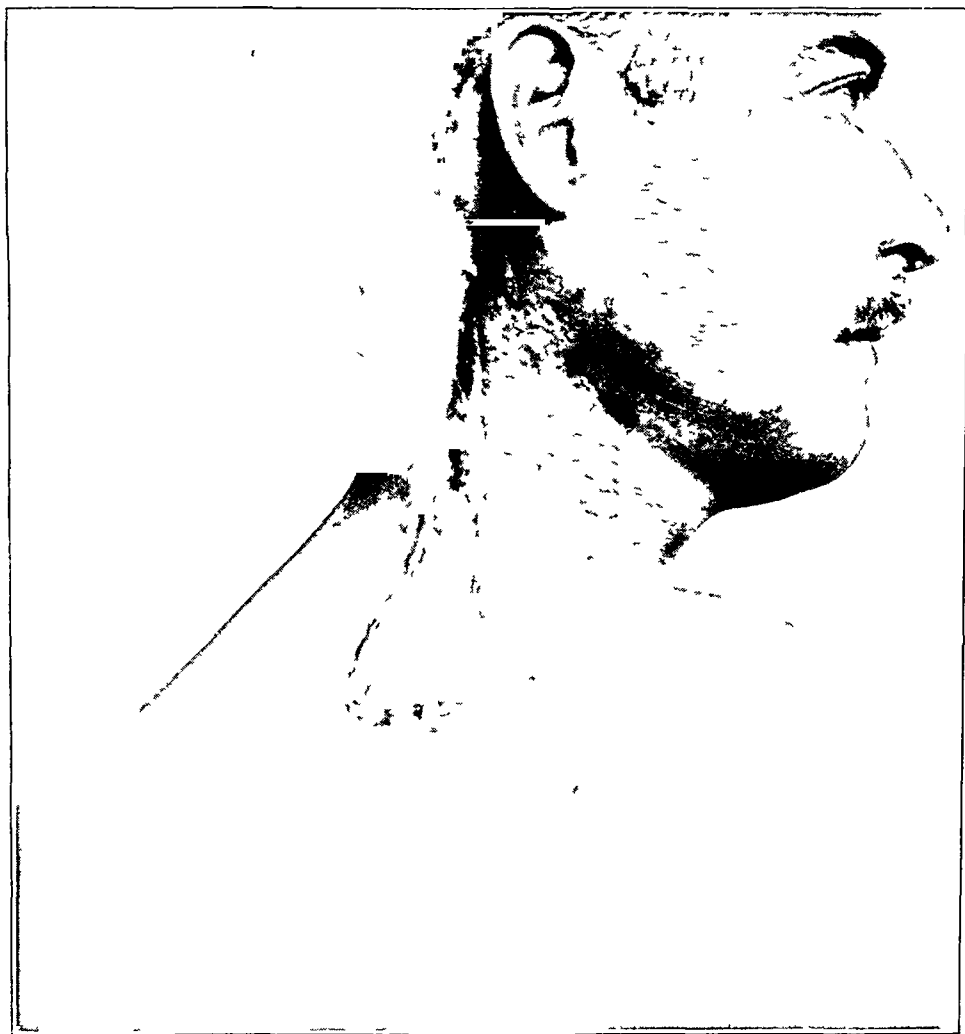


Fig 19—Scar of original incomplete operation, performed one year previously for tuberculous adenitis, spinal accessory nerve had been divided, patient sought relief from pain and disability due to trapezius palsy rather than from rapid local recrudescence of disease, scar of radical operation performed through composite incision eight months ago indicates poor healing occasioned by preceding operation

serous exudation and edema. Accurate hemostasis is imperative. Drainage is not always necessary, but if small soft tubes are used and removed early, smooth healing is more certain. Accurate approxi-

mation of the skin incisions minimizes scars. Silk in the long run is far more dependable for ligatures and sutures than catgut, if it is as fine as possible, tied in three knots, and the ends cut very short. Dressings must be ample and soft to equalize pressure. Gauze, well moistened in warm glycerin and applied next to the wound, encourages hyperemia and the discharge of serum. It also prevents gluing of the gauze to the skin and greatly facilitates the first dressing on the third day. The earliest reactivation compatible with healing is desirable. Exposure of the field of operation to sunlight or to electric light is advantageous if not overdone. Massage can usually be started within ten days. Manipulation should be gentle at first, gradually becoming

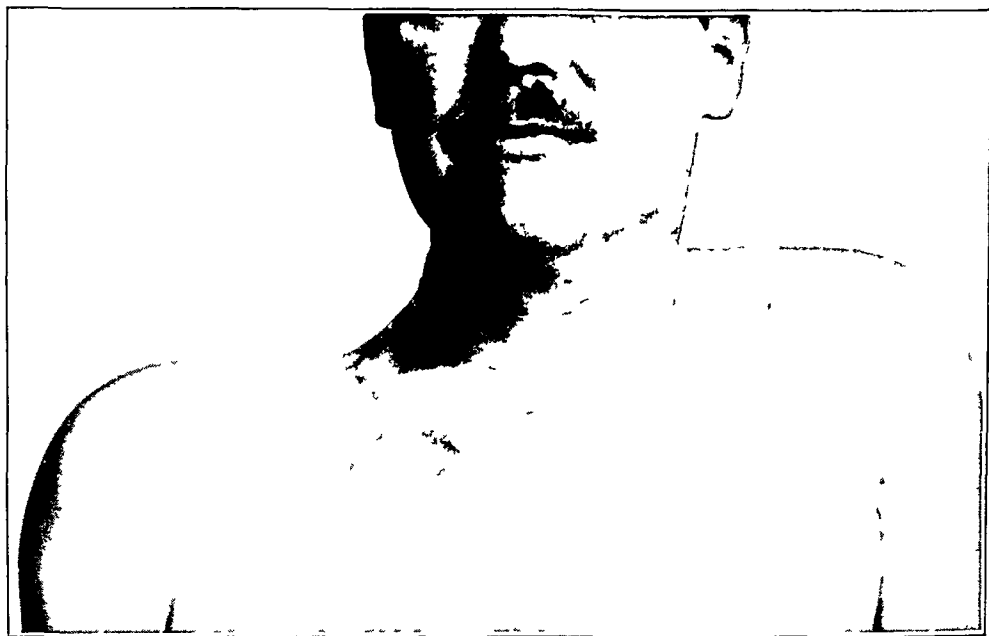


Fig. 20—Anterior view of patient shown in Figure 19, illustrating partial effect of eleventh nerve palsy. The nerve had been reunited at the last operation. There is enough recovery of function to relieve pain, and the disability is less.

more forceful to help loosen the deep adhesions and to promote formation of compensatory blood and lymph circulation.

A complete excision of regional glands is possible only when more than the tissue in which they lie is removed. The glands which determine the limits of a cervical dissection are indicated in Figure 1. The upper boundary of both superficial and deep groups is above the level of the jaw. It includes most of the submaxillary and the lower portion of the parotid salivary glands and the tissue overlying the mastoid. The anterior boundary is to the opposite side of the midline. The posterior boundary lies superficially, an inch (2.5 cm.) or more behind the anterior margin of the trapezius, and extends deeply from

the skull downward behind the trapezius and clavicle to the axilla. The inferior boundary anterior to the clavicle extends from below the suprasternal notch outward to the trapezius, posterior to the clavicle, it reaches from the jugulosubclavian juncture to the lower limit of the posterior boundary beneath the trapezius. Deep limits are the cervical muscles and include the spaces around and at times between the cords of the brachial plexus and that posterior to the great vessels. The

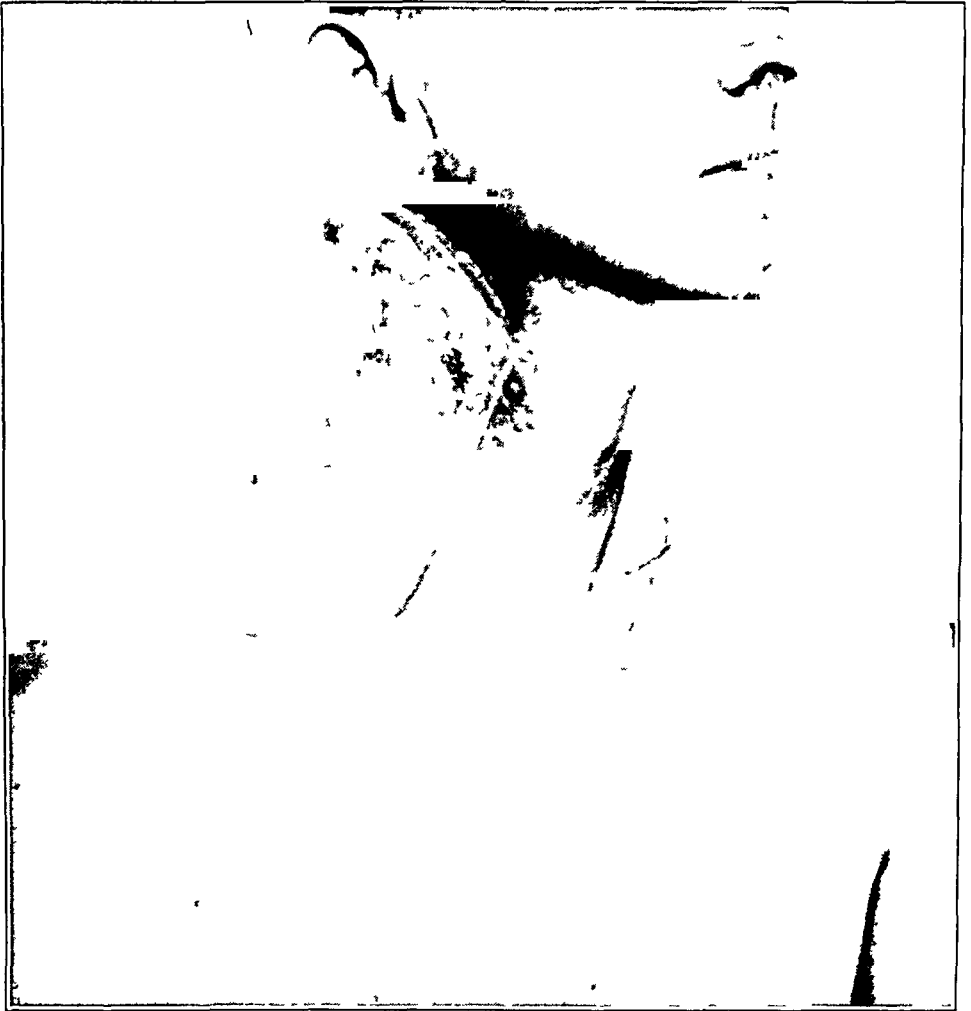


Fig 21—Bastianelli incision made four years ago in a removal of tuberculous lymphomas of so malign a type that the sternocleidomastoid had to be excised to make a complete operation possible, resulting in excellent healing

superficial limit is the platysma muscle. Preauricular and occipital glands are removed only when involved and are approached through separate incisions.

Some of these gland groups are particularly noteworthy since they are easily overlooked and this neglect has led to failure to obtain



regional recovery Those lying behind the upper attachment of the sternocleidomastoid muscle, between the internal jugular vein and the mastoid, are often diseased and impalpable This is also true of the glands back of the angle between the sternocleidomastoid and trapezius muscles and extending downward behind the anterior margin of the trapezius to join with the postaxillary glands in front of the subscapu-

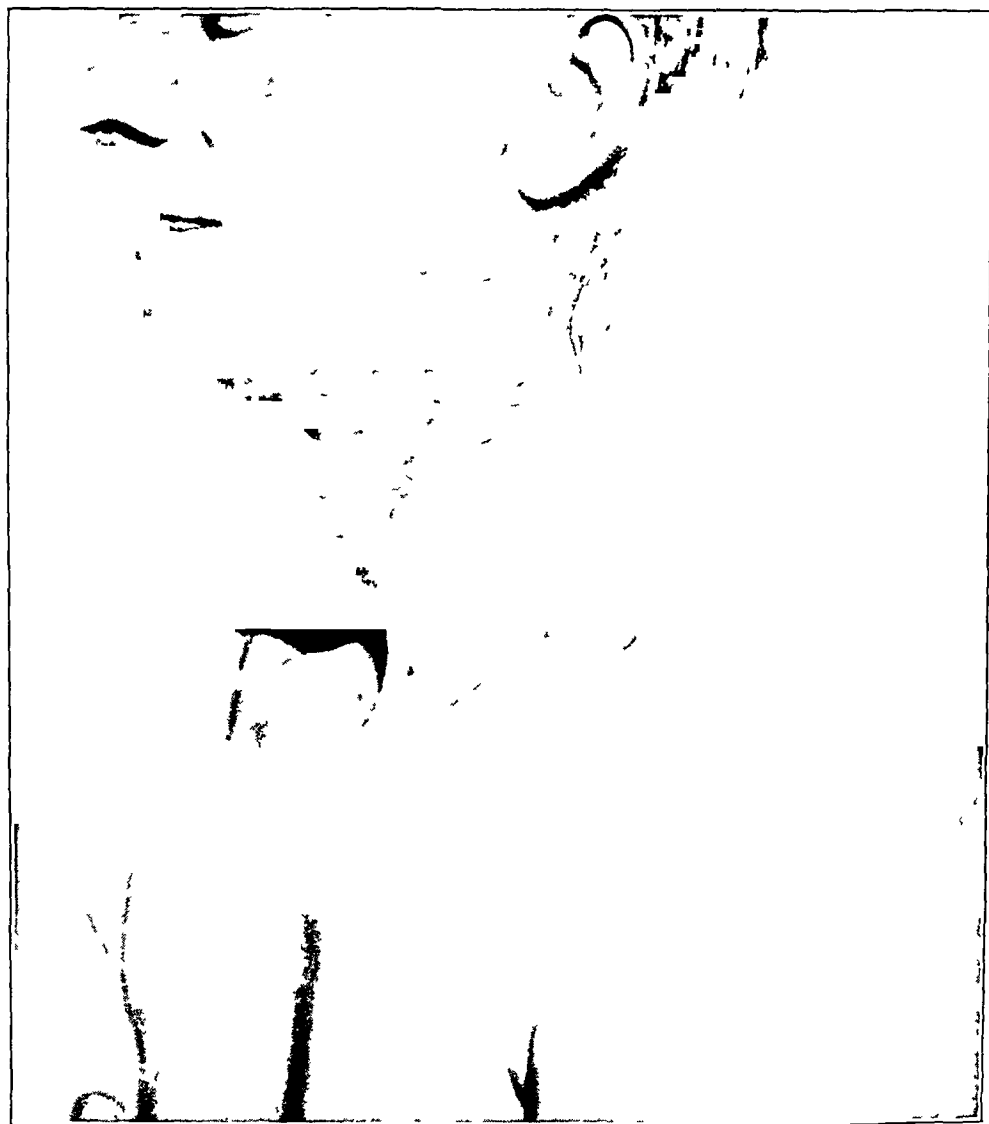


Fig 22—Opposite side of neck shown in preceding illustration, quite as radical an operation was performed two weeks later through a composite incision with equally good healing and leaving a much less objectionable scar, no recurrences on either side

laris muscle The glands lying near and between the cords of the brachial plexus communicate with axillary glands behind the plexus and mesial to those just described The middle part of the subclavian chain com-

municates with the axillary glands anterior to the plexus. The outermost glands of the subclavian chain communicate with axillary glands lying upon the subscapularis muscle as indicated above. The innermost are in the pathway between the neck and the mediastinum. The more superficial anterior glands are not shown in the diagram in order to avoid complications. They make necessary the removal of tissue beyond the midline in order to protect the other cervical region. A group of glands is commonly present below the middle of the clavicle, anterior to the pectoralis major muscle upon its fascia, or lying in a



Fig 23—Recovery from tuberculous adenitis occurred in this patient in spite of incomplete operations. One radical excision would have left no more scar, reduced total disability, and would have given greater assurance of recovery.

space between the muscle bundles. This group communicates above with the cervical glands through lymphatics placed anterior to the clavicle, and directly posteriorly, it communicates with the axillary glands. It is to be borne in mind that the distribution of glands has been determined entirely by repeated morbid anatomic observations.

Certain structures lying within these limits must be preserved (Fig 2) to assure the function necessary to protect local resistance. The sternocleidomastoid and omohyoid muscles seldom require com-

plete removal and then because of periadenitis or invasions. Glands are rarely present in the lower tendon and adjacent muscle of the sternocleidomastoid, and, if not involved at the time of operation, seem to be negligible. Both of these muscles are useful in repair, both have sufficient blood supply through tendinous branches to make them viable though they are otherwise denuded. It is unsafe to divide them to



Fig 24—Scars of multiple operations performed to remove lymphomas of Hodgkin's disease. This man has made a symptomatic recovery in spite of incomplete excisions. Scar where preauricular glands were excised may be noted. This patient would have recovered more promptly after one complete extirpation and at least two recurrences would have been prevented had the lower margin of the parotid been removed. The tan on his shoulders indicates persistent after-care even though he survived service with the A. E. F. and was discharged in splendid physical condition. His recovery is attributable to the splendid physical condition maintained and illustrates what can be accomplished in spite of surgical errors.

facilitate dissection and to suture later, as necrosis or progressive cicatrization is liable to follow. Blood and lymph circulations are reestablished rapidly and adequately if the carotids and the deep jugular vein are spared. Plastic operations upon these vessels are preferable to ligation. Leakage from an injured thoracic duct that is not noted at operation declares itself promptly and should be controlled immediately. Pressure packing with hot cotton usually suffices. Protection must be given to nerves during both operation and healing. Injury to the spinal accessory nerves is not always avoidable. If reunion after division is impossible, implantation of the proximal trunk



Fig 25—This boy has survived multiple incomplete bilateral cervical excisions of Hodgkin's lymphomas, with division of both spinal accessory nerves, followed by equally ill-advised exposures to the roentgen ray. Two complete operations were finally performed through composite incisions, nerve repair was unsuccessful. The subsequent healing was poor as the scars indicate. Living in the open has made the difference between a hopeless and a good prognosis. Onset of disease six and a half years ago, last operation one year and four months ago.

into the trapezius muscle may obviate paralysis. Drop shoulder due to trapezius paralysis does not appear for several weeks. It is unsightly, a decided handicap to activity, and is frequently painful. Protection against this handicap is so important that the communicating branches between the cervical plexus and spinal accessory nerves should be saved if possible. Injury to the hypoglossal nerve during

operation is rare, but as the result of cicatrization it is not uncommon, particularly if a Bastianelli incision is used. It must be remedied at once or it becomes a fatal complication. The pneumogastric nerve is seldom injured by operation or cicatrization, though it may be affected by pressure exerted by disease. The phrenic nerve is rarely endangered, and though injuries to it may not cause notable paralysis of the diaphragm, it should be protected. Complete facial paralysis has not occurred, but paralysis of the lower lip is the rule. The small branch of the seventh nerve to the lip can sometimes be saved. Its

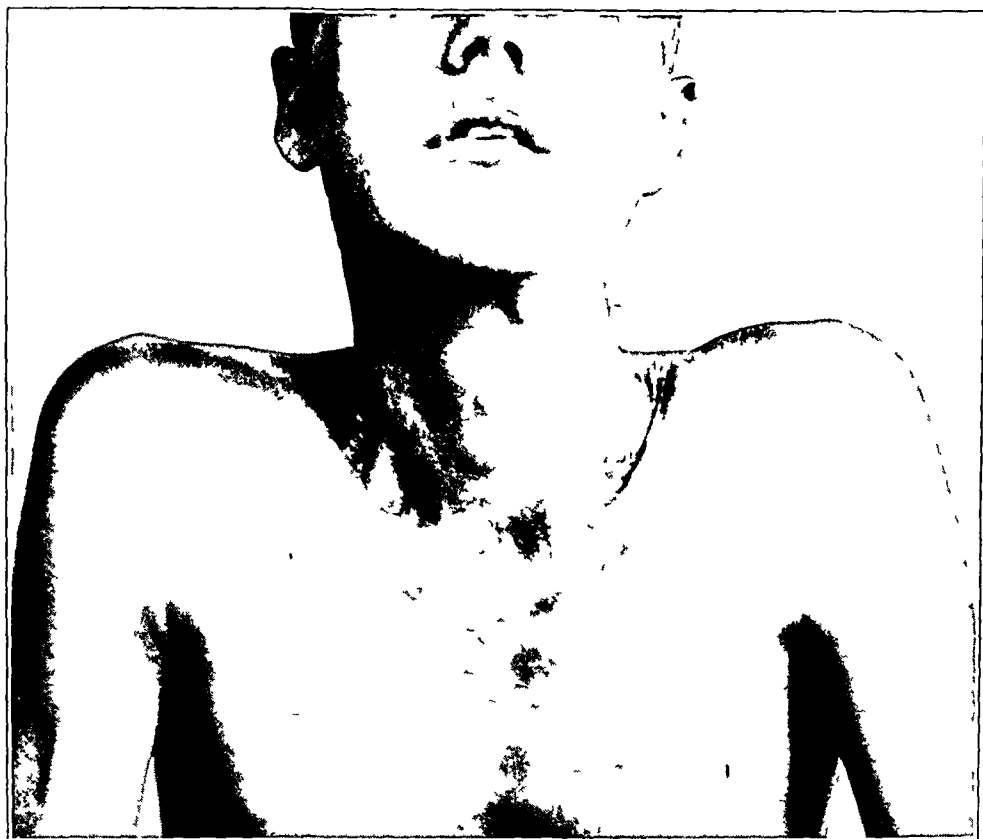


Fig 26—Anterior view of patient with double spinal accessory palsy, with shoulders elevated

preservation is of little consequence as regeneration is virtually constant. Similarly, the nerve supply to the omohyoid, sternohyoid and sternothyroid muscle should be saved if possible. The lingual branch of the fifth cranial nerve may be traumatized when the submaxillary gland is completely excised and especially when local anesthesia is employed. Subsequent paresthesias are uncommon, but they are so disagreeable when they do occur that the nerve should be carefully protected. Sensory branches of the cervical plexus require no consideration.

Incisions (Fig 3) are determined partly by the exposure required but more by the character of the healing likely to follow. The Bastianelli incision makes possible a rapid reflection of skin flaps and gives excellent exposure, but immediate healing is uncertain. The longitudinal branch is later liable to be the site of a dense band of scar tissue which interferes with motion, is irritated by a collar, and is unsightly. A composite incision, extending backward from the lobe of the ear, downward posterior to the anterior margin of the trapezius and anteriorly in natural skin creases to the opposite side of the neck, has been more satisfactory even if flap reflection is more tedious and the exposure less pleasing.



Fig 27—Posterior view of patient with double spinal accessory palsy with shoulders elevated, lifting strength much below normal

The skin flaps should not be dissected too thin. Routine removal of the entire platysma muscle is unnecessary. A margin of this muscle along the skin incision should be saved to aid both in closure and in healing. If a composite incision is made, the skin posterior to the vertical portion is not reflected so as to assure a normal circulation on one side of the line of suture. Very occasionally a separate submental incision may be made to assure a more accurate excision of these glands. The Bastianelli incision, appropriately modified is preferable for operations consisting of two stages or more, when a one-stage operation is known in advance to be undesirable.

The concentric dissection (Fig 4) is made fairly uniformly so that heat and pressure in one area will control oozing, while another part is being excised. One line of dissection is frequently easiest and is thus discovered. This is a matter of importance in the presence of considerable involvement with dense adhesions. The spinal accessory nerve is exposed early and protected from injury. After the tissues

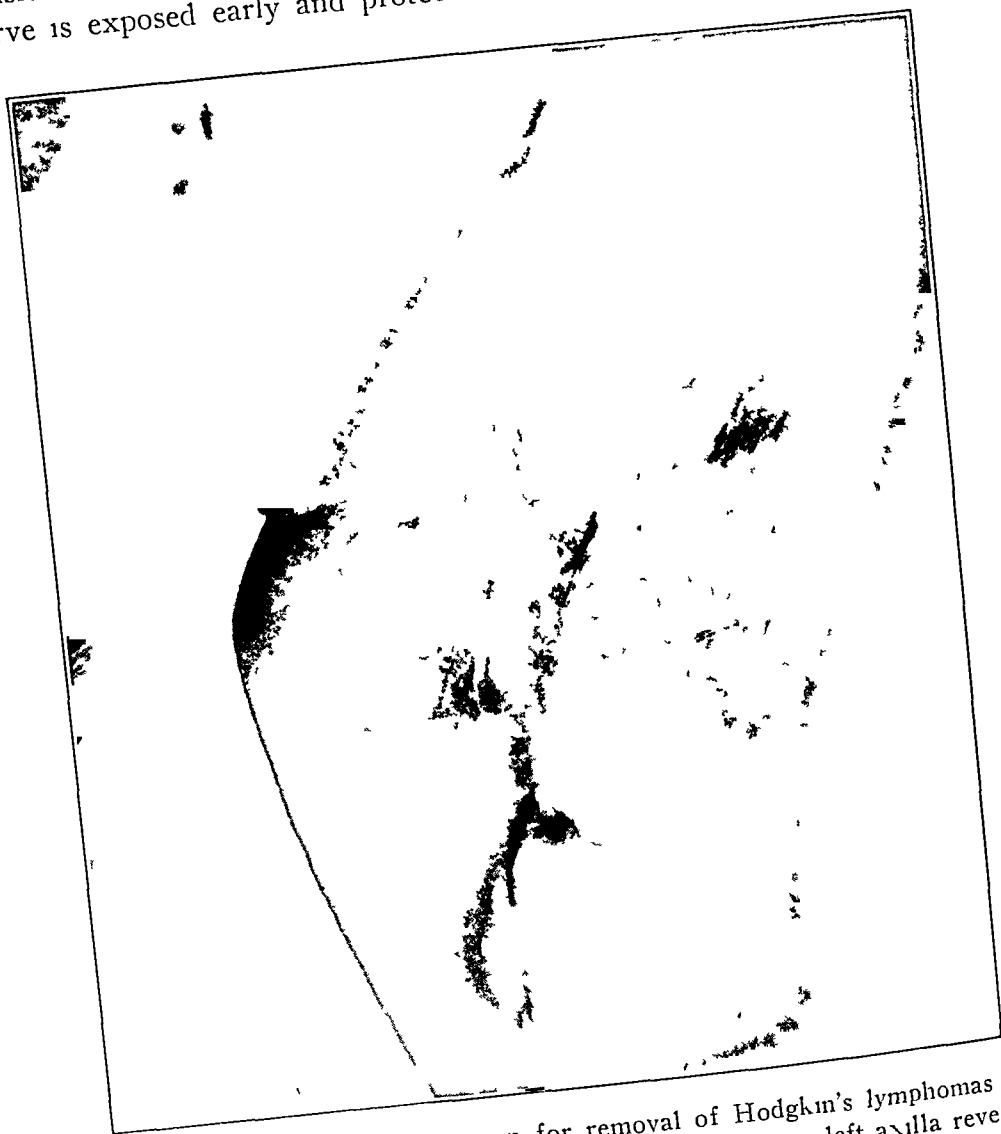


Fig 28—Scar of Kocher incision for removal of Hodgkin's lymphomas five years and eight months ago. Glands recently removed from left axilla revealed common, nonspecific adenitis. Example of regeneration and normal reaction of lymph glands.

overlying the sternocleidomastoid muscle are divided, they are dissected off so that the entire muscle is exposed. Those reflected mesially are later passed laterally beneath the muscle and the entire mass is removed in one piece. Usually it is safest to complete the dissection along the deep lower boundary after the remainder of the excision has been

made. The chief danger, especially in the presence of periadenitis, lies in venous injuries while the subclavian and lower jugular veins are being freed. If all of the rest of the dissection has been completed, this danger is minimized and prompt exposure of an injured vessel is assured. Figure 5 shows a satisfactory method of obtaining the tissues leading from the neck to the mediastinum. Traction from above, with careful blunt finger manipulation, makes possible a far deeper removal



Fig 29—Opposite axilla of patient shown in Figure 28, no functional impairment on either side

than would be surmised. Accurate clamping as the dislocated glands are cut free eliminates active bleeding. Sharp dissection cannot be used to advantage in removing the fat lying between the cords of the brachial plexus or that filling the space between the clavicle and trapezius, anteriorly and the subscapularis posteriorly. Gauze dissection is safe if the resisting bands are clamped slowly, cut and ligated. Motor nerves are thus recognized and troublesome bleeding due to retraction of severed vessels is prevented.



The first step in closure is to inspect every part of the wound for bleeding and for gauze or cotton packing. Occasionally, a few stitches will be needed to check oozing from the raw surface of the parotid. Muscles (Fig 6) are sutured so as to cover exposed nerve trunks and to provide as complete and as even a floor for the skin flaps as possible without causing too great tension. Soft drainage



Fig 30—Scar of Kocher incision used in removal of Hodgkin's lymphomas four and a half years ago

tubes are inserted and fixed so they can be withdrawn the next morning without disturbing the bandage.

Interrupted stitches are used to approximate subcutaneous tissue, using platysma wherever possible, in such a manner that the skin edges are overapproximated. Subcutaneous sutures are so inserted (Fig 7) that the knots are placed inward, away from the skin. The

skin stitch illustrated gives splendid approximation, but possibly contributes to keloid formation

Large amounts of elastic dressings are placed upon the warm glycerin gauze next to the wound and the head inclined toward the operated side, rotated toward the opposite side and firmly fixed. This uncomfortable position should be maintained for four or five days

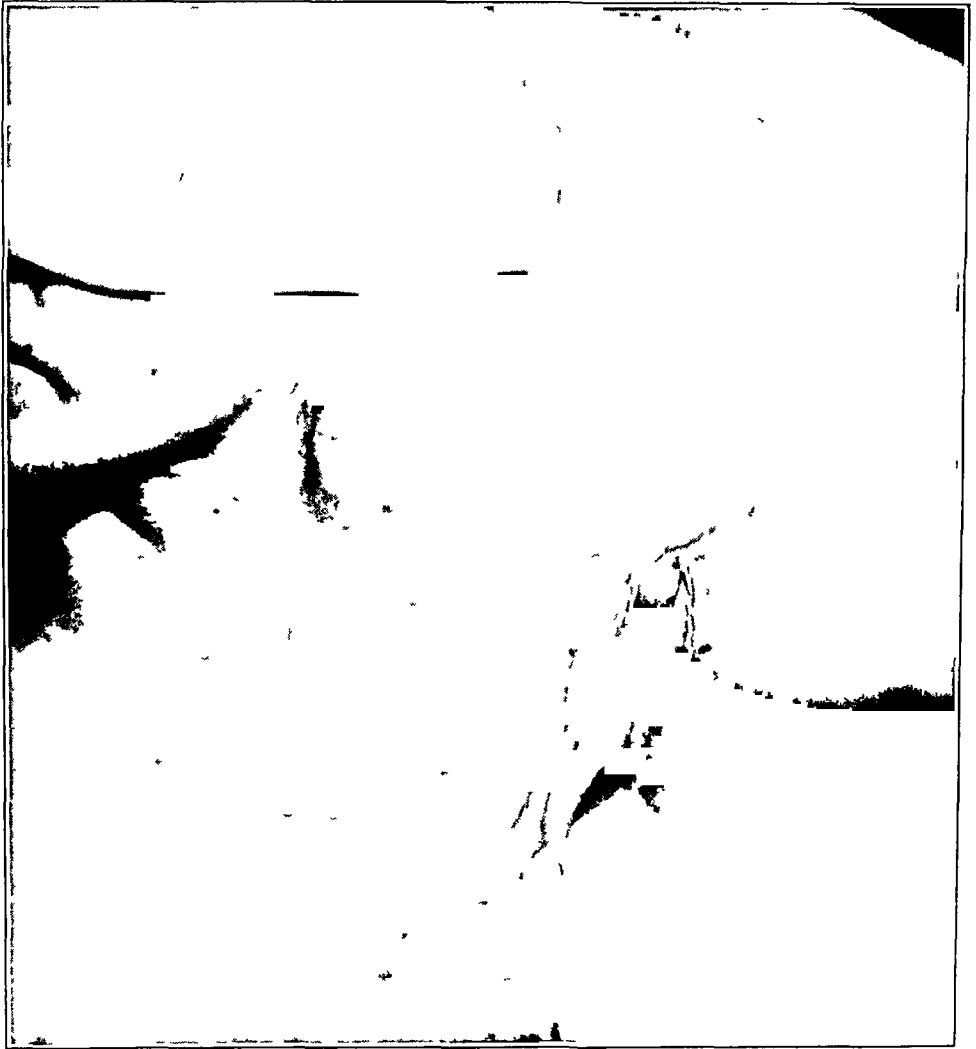


Fig 31—Scars of composite incision used to remove an endothelioma from arm, and to excise the axillary glands a year ago. This patient has not regained function in the pectoralis major which explains limitation of motion

Patients should be encouraged to sit upright as soon as anesthetic dizziness has disappeared and to get out of bed on the second day

It has been asserted that these operations are best performed with local anesthesia. My experience has taught that ether anesthesia given with the Connell apparatus is the most satisfactory method for

the patient After the first half hour the anesthesia should become analgesia A more accurate dissection can be made than is possible with local anesthesia The patients are conscious before closure is complete, and, as a group, show little of the bad effects of ether. Morphine is given before and after operation

Extirpation of axillary glands is far easier than that of cervical glands, but postoperative repair is less satisfactory The glands that



Fig 32—Patient showing how little a composite incision shows even when there is extensive keloid at thickening in the scar

determine the safe limits for excisions are indicated in Figure 8 The upper boundary is superficially above the clavicle and includes the fascia over the sternocleidomastoid and trapezius muscles, deeply it extends from beneath the sternoclavicular ligament outward to the latissimus dorsi tendon, in front of the vessels up to the clavicle and behind the nerves upward to include the upper subscapularis margin Laterally, the boundary is superficially the anterior margin of the

latissimus dorsi and deeply the fat lying anterior to this muscle. Inferiorly, the boundary is determined by the disease. In cancer of the breast it includes the upper rectus fascia and extends thence outward to the latissimus dorsi. The mesial boundary extends from the opposite pectoralis major muscle and in cancer includes the entire



FIG 33—Result three years after radical operation for mammary cancer. The pulling band in the axilla could have been obviated and better function obtained if Halsted's operation had been performed.

homolateral pectoralis major, in the other affections only the upper portion of its fascia. Superficially, the limit is the subcutaneous fat and deeply, it is the ribs and intercostal muscles.

Gland groups, especially noteworthy because they may be overlooked and may lead to avoidable extension or regional recurrences, are all easily removable. Those lying close to the sternal attachment of the pectoralis major communicate with the mediastinum and are removed if the muscle is cut close to its origin. No serious bleeding

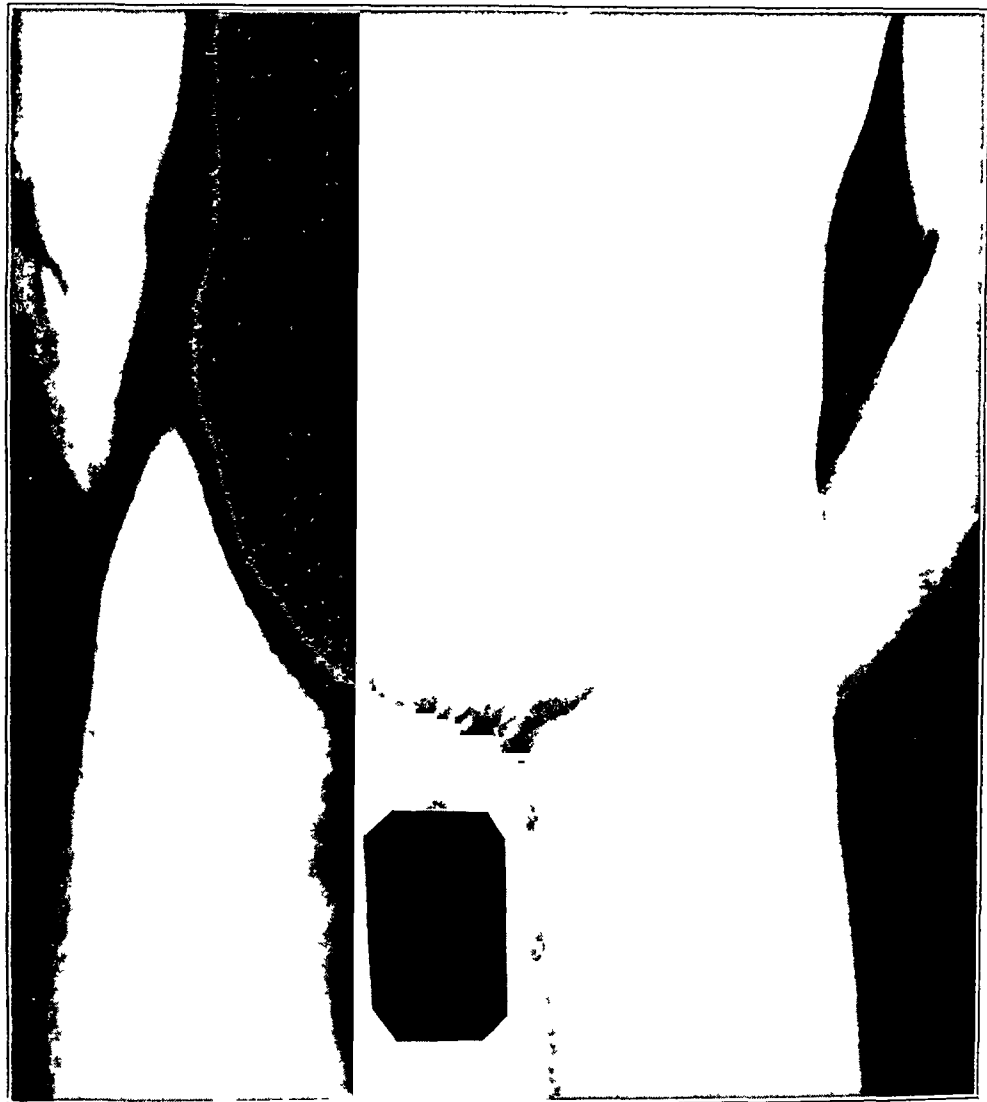


Fig 34—Scars of operations performed six and a half years ago to remove superficial glands from both groins because of Hodgkin's disease. This is the same patient shown in Figure 30. He served with combatant troops in France and at present is disease-free.

need follow if perforating branches are clamped before they can retract. The glands located above and behind the axillary vessels are in direct communication with the neck and those in the fat anterior to the latissimus dorsi are, similarly, gateways to the lymphatics in

the spinal canal. A gland or two is irregularly present within the mammary gland near its outer margin but occurs often enough to require excision of this portion of the breast in noncancerous affections. Like the preauricular and occipital glands in cervical involvement, there is a group lying over the infraspinatus muscle just below

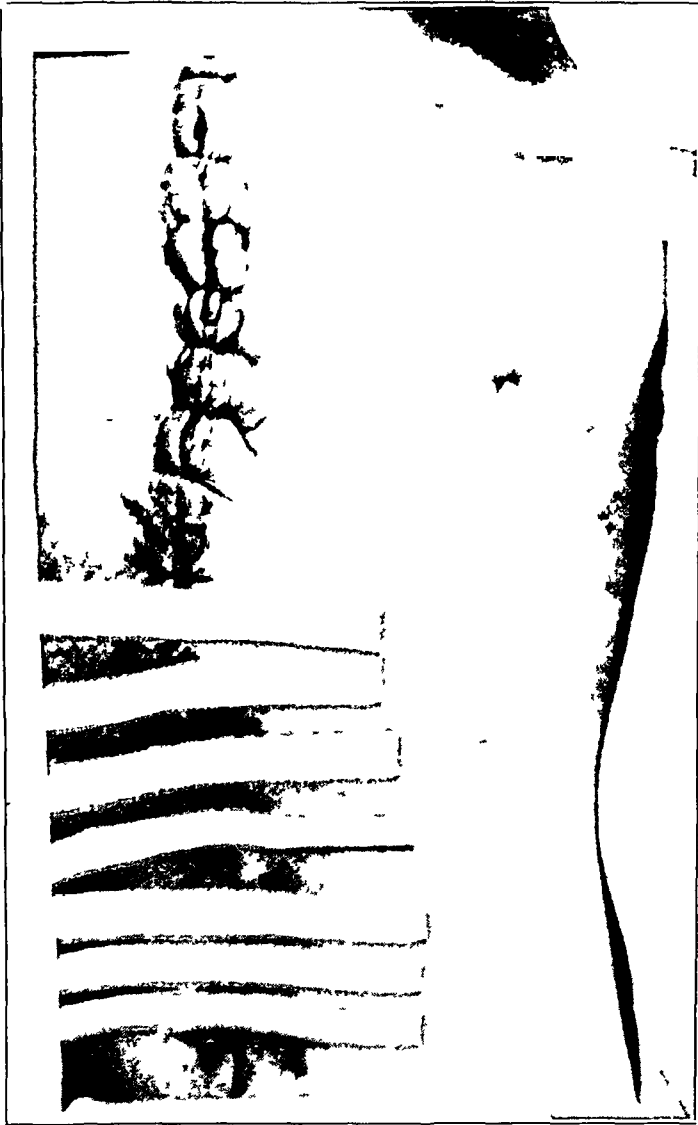


Fig. 35—Wound on second day after excision of deep and superficial inguinal glands, sutures have been removed from lower half of incision and adhesive strips applied to prevent separation of skin margins

the spine of the scapula that require removal only when involved and are then secured through a separate incision.

Structures essential to function that should be spared in axillary dissection are few. Complete excision of both pectoral muscles is indi-

cated in operations for mammary cancer. In other affections the pectoralis minor alone is removed. Preservation of the external anterior thoracic nerve is usually impossible. Contraction of the pectoralis major may return in a few weeks even when it is divided. The posterior thoracic nerve and the branch to the latissimus dorsi should usually be saved. Main axillary vessels should be saved to preserve function and to give direction to regenerating lymphatics. Injury to the cephalic vein should be avoided, as it is of great value in compensating if the axillary vein is destroyed and in aiding the regeneration of lymphatics.

Removal of dangerous tissue required in operations for mammary cancer (Fig 10) demands incisions not needed in the excision of axillary glands involved by other malignant diseases. Only the latter operation will be described in detail. The reader is referred to Halsted's description of his radical operation for cancer of the breast for the methods that both give the greatest protection and assure the most satisfactory functional recovery.<sup>2</sup> Longitudinal incisions in the midaxilla are favorable neither for exposure nor for healing. An exaggerated Kocher incision gives adequate exposure and heals fairly well. The composite incision gives better exposure, heals well, is less unsightly, and can easily be varied to suit conditions.

After skin flaps have been reflected and protected, a concentric deep dissection is started. A superficial reflection is begun above the clavicle and along the mesial boundary that includes all tissues down to the muscles. It extends downward in women below the upper mammary margin and includes the lateral border of the breast, in men the pectoral fascia is more widely removed. When this part of the dissection is finished, the upper anterior surface and entire lateral margin of the pectoralis major is exposed. The tendinous insertion of its sternal portion is then divided fairly close to the humerus and as the under surface is separated this part of the muscle is reflected toward the opposite side (Fig 11), giving abundant exposure. The inferior boundary of incision at the lower margin of the pectoralis major is carried laterally onto the latissimus dorsi. The whole of the mesial margin of this muscle is exposed, the muscle retracted and the underlying fat dissected toward the midline. Removal is henceforth from above downward. The clavicular portion of the pectoralis major is retracted, the insertion of the pectoralis minor divided and all of the fat above and anterior to the vessels dissected downward. The axillary vein is freed from beneath the falciform ligament out-

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<sup>2</sup> Halsted's discussion of the causes of postoperative elephantiasis is invaluable in connection with extirpation of lymph glands, Footnote 1, *Developments in the Skin-Grafting Operation for Cancer of the Breast*, J A M A **40** 416 (Feb 8), 1913.

ward and its branches ligated, except the vein accompanying the external respiratory nerve. Upward retraction of the vein makes possible the removal of fat lying behind and above, first mesial to, and then lateral to, the branch that has been saved. Discovery and protection of the two nerves is easy. The remaining excision of the single mass of tissue is rapid. This dissection removes all dangerous gland-bearing tissue and breaks lymphatic connections with spinal canal, neck, mediastinum and opposite axilla.

Deep closure (Fig 12) includes fixation of the pectoralis major to the chest wall with a few mattress sutures of catgut to help obliterate a large and dangerous dead space, suturing the tendon at its line of division and stitching the lateral border to the anterior margin of the latissimus dorsi. Drainage of these wounds is imperative. The superficial closure is similar to the cervical (Fig 13).

Bandages include the arm when the pectoralis major is saved and active motion is deferred until after the fifth day. Function is nearly normal in a few weeks.

Removal of inguinal and iliac glands is easy and immediate healing is satisfactory provided the technical niceties are observed in every detail. There is postoperative edema of the genitalia of some duration that is particularly troublesome after bilateral operations. A distinction is to be made between superficial and deep involvement (Fig 14). The superficial glands extend from above Poupart's ligament to below the midthigh and from the pubes to the anterior superior spine, the deep involvement from beneath Poupart's ligament to the sacral promontory. Limits for superficial and deep excision are obvious. There is difficulty in deciding when to extirpate the retroperitoneal glands because of consequent edema of the genitalia if operations are bilateral. A few structures should be spared. The long saphenous vein is valuable in helping regeneration of lymphatics. Sparing the external cutaneous nerve prevents annoying anesthesia. Deep epigastric vessels can sometimes be saved, but ligation seems to make no difference in the healing and provides better exposure (Fig 15).

Skin flaps are separated and protected with particular care. The superficial dissection is made concentrically. It removes all the tissues from above the level of the internal ring down to the fascia of the external oblique muscle (Fig 15). The fascia lata is excised as close to Poupart's ligament as a sufficient protection against hernia permits. Separation of glands from the femoral vein, notably at the juncture with the saphenous vein, may be a little troublesome. Otherwise the dissection is simple.

Incisions are determined by the healing (Fig 16). If made with convexity inward, a skin slough is probable, a slight convexity out-



ward is safe if located slightly to the mesial aspect of the thigh. If only the superficial glands are to be removed, the incision extends from just above Poupart's ligament to just above the midthigh, if a deep dissection is contemplated, the upper limit is extended to the level of the umbilicus.

Exposure of retroperitoneal glands is obtained by a herniotomy incision. The fascia of the external oblique muscle is split just above the upper margin of the external ring. The spermatic cord, protected against injury, is displaced upward without avoidable exposure and separation. The internal oblique and transversalis muscles are separated outward from Poupart's ligament and displaced upward (Fig 17). After the deep epigastric vessels are ligated or stretched and displaced, the peritoneum is separated and elevated. Fat and glands are removed from below upward, largely by blunt dissection. Resistant bands are made tense by traction, divided between clamps. It is thus possible to make safely a clean dissection as high as the promontory of the sacrum (Fig 15).

Closure (Fig 18) of a wound created for deep excision is like the Ferguson-Andrews herniotomy closure, except that the lower leaf of the external oblique fascia is placed superficially in order to transplant the suture line upward, away from the zone of danger of poor healing. Extra care is to be taken to obtain a smooth muscle floor. Excision of fascia lata and the construction of a muscle floor make possible immediate healing and the development of a compensatory circulation. Later the skin scar becomes freely movable, the subcutaneous fat is smooth and the fascia lata seems to regenerate. The deep retroperitoneal space obliterates itself so that drainage is unnecessary if the ligation of vessels has been accurate and oozing has been controlled by hot packs. A small tube should be inserted at the lower angle of the skin incision and carried upward along the inner side of the sartorius to just below Poupart's ligament. It should be removed the first day. Abundant elastic dressings and a snug spica are needed to maintain pressure and to hold the thighs in flexion. The foot of the bed should be elevated as high as tolerable.

These patients should be out of bed in a week or ten days and begin at once to walk a little, then to sit with the feet elevated until the swelling is less. If this method of exercise is coupled with systematic massage, recovery is hastened.

A few photographs are reproduced herewith to show the healing and the functional results following operations performed according to the methods described. They have been selected as fair examples of cases that have gone long enough to indicate the probable accomplishments of this type of surgery.

## COMMENT

A study of Hodgkin's disease begun fifteen years ago developed a deeper interest in other lymph gland affections. After a few years the investigation was broadened by a realization that Hodgkin's disease possesses characteristics of both a granuloma and neoplasm and is a sort of connecting link between them. A comparative study of tuberculosis, Hodgkin's disease and cancer was undertaken to learn from their pathogenetic activities and consequent defensive responses whatever might help to solve the chief problem—a means to more effective treatment.

Results of these studies have been published<sup>3</sup> at intervals and are the basis of this paper, which would have become overlong had the evidence again been presented. Clinical and experimental data indicate variations in susceptibility to the diseases in question, and that age, sex, race and environment are to some extent influential. Moreover, there are variations in individual susceptibility to the ravages of the diseases, once they are established, which are determined by other influences than that of duration of the ailment. Two conclusions have been drawn. First, there are defensive reactions concerned, which are responses to irritation of disease, and, second, effective treatment must reduce irritation and conserve defensive powers.

The offensive mechanisms have many parts in common. They induce far less obvious responses than do more acute diseases because the reactions are of less degree and of far greater duration, like the ridges in the bellows of an accordion that tend to disappear when the ends are more widely separated. Nevertheless, certain features are well established. Living irritants, bacteria or morbid cells, extend from a primary focus or portal of entry through lymphatics to lymph glands or lymphadenoid structures in which, if the parasitic cells are able to develop, secondary foci are formed from which further extension similarly occurs. Hematogenous dissemination is also a possibility or perhaps a probability. In addition, there is a constant dissemination of soluble irritants produced by the action of morbid cells. The toxemia affects the hematopoietic system, the nervous system, liver, kidney and heart muscle. Thus arise the anemia, depression and other manifestations that make up the disease picture.

Defensive responses depend upon intensity of the irritation and reactivity of the host. There may be much or little lymphangitis and perilymphangitis, lymphomas may develop rapidly or remain obscure, anemia may be a first sign or a very late one, mental depression and

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<sup>3</sup> Yates, J. L. *Tr. Western Surg. A.* **26** 373, 1916, *Surg., Gynec. & Obst.* **27** 156 (Aug.) 1918.

physical weakness may be disproportionate to the amount of disease, febrile responses may be prominent or absent, or in Hodgkin's disease they may be pathognomonic

There are two reactions of great importance from the standpoint of treatment. Moderate irritation of lymphadenoid tissue causes stimulation of lymphoblasts which provokes not only an increased production of lymphocytes, but, what is still more significant, it leads to a formation of something which simulates an antibody, in that it possesses protective value. Just why an abundance of lymphocytes about the local lesions and in the blood stream indicates a more competent defense is not clear, but it has held so accurately in our studies that it is accepted as a fact.

A working hypothesis that will be satisfactory until the functions of the lymphocyte are discovered, because it has been substantiated by observations, is that good defense is typified by a moderate lymphocytosis. By the same token, effective therapy preserves or precedes increased lymphoblastic activity that will be insufficient to cause lymphoblastic exhaustion.

This hypothesis will hold whether or not the lymphocyte is found to be of value in defense, because active lymphoblastic tissue is invaluable. Newly forming lymphadenoid tissue is both intrinsically hyper-resistant and beneficial to the entire organism. Lymphoblastic structures undergo the compensatory hyperplasia seen in other varieties of glands if a considerable proportion is suddenly removed and the remainder is relatively normal. I believe I have found that a physiologic response of this nature consequent upon regional lymph glandular extirpations or splenectomy, followed by exposure to sunlight, is the best way, if not the only way, to induce desirable lymphoblastic stimulation.

These diseases do not, as a rule, progress steadily and it is improbable that uninterrupted development, even in the ultra-acute and chronic forms, is more than the rarest of exceptions. The alternating phases of growth and retardation in disease evolution are believed to be due to periods when the defensive reactions are nearly adequate or quite inadequate. If spontaneously they became and remained adequate, the disease would cease to be malign, which is the usual course in tuberculosis. Should the irritation be early and sufficiently reduced by extirpation, as it may be in cancer and in Hodgkin's disease, the living irritants are rendered innocuous and remain latent until defense is subsequently disturbed and a recrudescence is established. Renewed activity can occur after thirty years of latency in cancer,<sup>4</sup>

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<sup>4</sup> Finney in Keen, W. W. *Surgery Its Principles and Practice* Philadelphia W. B. Saunders 3 603, 1908

and I have seen it appear in a Hodgkin's "cure," eleven years after the disease was supposedly overcome

Attention is too easily focused upon local reactions and too little consideration is given to the more general responses. Integrity of the entire circulatory system is requisite to recovery, not merely of the lymphoblastic fraction. This includes the bone marrow and the heart muscle directly, and less directly the liver and kidneys. However it may come about, whether through age, unhygienic living, or intercurrent influenza, etc., impairment of the hematopoietic structures predisposes to a serious break in defense.

Treatment consists of eradication of local disease and conservation of hematopoietic function. My experience has taught me that complete excisions are trustworthy. Adjacent regions may become involved when resistance is dissipated and widespread dissemination follows, yet the excised areas remain free. Failures to obtain regional cures have been due in my hands to partial excisions. I believe the reason that operations in the treatment of Hodgkin's disease are in ill repute is because they have not been thoroughly performed. Incomplete operations are still being performed in combating cancer because the greater advantages of radical surgery have remained undemonstrated.

I am opposed to routine radiation for three reasons. It is an uncertain means for the elimination of a primary focus. It has never controlled malignant lymphomas permanently. It has a deleterious effect upon hematopoietic function when too large doses are given. Dose measurement is difficult. An estimation of a patient's susceptibility to roentgen-ray is guesswork.

I have seen patients who have boasted of the phenomenal exposures to roentgen ray and especially to radium that they have been able to withstand. Their blood showed the lethal effects which a short time demonstrated. Radiation will reduce the white cells in leukemia. It will do so in the absence of leukemia. It will also produce an aplastic anemia. Time was when enthusiasm for radiotherapy was alone tempered by the danger of skin burns. It should be regulated now by the dangers of bone marrow burns.

Efforts to stimulate a production of lymphocytes, of erythrocytes and of blood platelets after the mother cells have become exhausted or destroyed have been unsuccessful. Life can be prolonged materially by repeated blood transfusions, particularly when radiation is being pushed energetically for palliation. Living in the open with exposure to sunshine is the surest and safest method for getting maximum benefits.

It must be recalled that radiotherapy is still in an experimental stage. Some excellent results, like the treatment of cancer of the cervix of the uterus, are now obtainable. Other real advances will be made. Experimental and clinical evidence indicates that radiation is least harmful when the lymphoblastic activities remain unaffected. Administered within this limit there may be some advantage to be obtained from postoperative treatment. If the dosage exceeds this limit and produces lymphopenia harm is being done, even though palliation of an otherwise unrelievable disease is the only aim.

#### SUMMARY

There are good reasons for the universal dissatisfaction with the results of present methods of treating malign diseases. Failures are partially attributable to late diagnosis and delayed treatment, but they are also due to a concentration of medical activities upon signs and symptoms of disease rather than upon the real factor that determines the outcome—the defensive capacity of the individual.

Progress is impeded at the present time by too great expectation from the searches and researches devoted to the discovery of 'cures.' A very natural and human desire for a panacea may one day be gratified, but, judging from the past, that day is still remote. Meanwhile the clinicians who are treating patients must make advances with the means at hand if they recognize their responsibilities and their opportunities. There is ample reason to believe that individuals vary in susceptibility to malign diseases and also in susceptibility to their ravages once they are established. Treating malignant diseases has accomplished relatively little. Treating the patient to decrease susceptibility has accomplished a great deal in tuberculosis and can be extended to other malign affections with but one risk—that of benefit.

A logical method might well be made to combine all that is known to be effective in the treatment of disease with all that is known to be beneficial in treating the individual. Such therapy could be called scientific, and no other. If it is to be adopted, we will have to stop drugging ourselves with statistics because scientific treatment can no more be determined by statistics than it can be instituted for them. Figures compiled today upon what seem to be facts, tomorrow have little foundation in fact. Results are proof, and when favorable results are obtainable, figures are no longer manipulated to establish that fact.

In combating disease that can persist throughout a patient's life and probably does so persist, it is manifest folly to speak of surgical cures or of cures of any kind. The term 'cure' implies permanency and when used in this way it is doubly harmful. It releases patients from their obligation to take care of themselves and absolves their physicians from

their lasting responsibility in what has become preventive therapy. Deaths due to avoidable mistakes in treatment are no less unfortunate whether they occur in ten days or in ten years.

We know that in following this line of treatment it has been possible for patients suffering from malign diseases to have lived longer than would otherwise have been possible. I hope that the operations that have benefited a small group of patients may enable other surgeons to initiate recoveries of greater duration in a larger number.

# THE VALUE OF ARTIFICIAL AIDS TO RESPIRATION IN "ACUTE OPERATIVE COLLAPSE OF THE LUNGS" (SURGICAL PNEUMOTHORAX) OCCURRING IN THE COURSE OF INTRATHORACIC OPERATIONS

AN HISTORICAL REVIEW AND A DISCUSSION \*

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THE TREND OF THORACIC SURGERY IN 1920 AND 1921

Impressed by the great volume and variety of articles on subjects pertinent to the surgery of the thorax, which have appeared in the current literature, I have endeavored to compile and classify the bibliography in order to determine, as far as practicable, the actual progress accomplished and the lines of advance as foreshadowed by the activities of the workers in our special problems

The great impetus given to thoracic surgery by the experience of the world war, so well emphasized by Dr Meyer in his presidential address, is still reflected in the current literature, and the vital issues raised by that experience continue to ride over the great tide of thoracic literature as its leading and dominant topics of discussion. In a merely tentative and incomplete estimate of the bibliographic references on thoracic surgery which have appeared during the last eighteen months, or from Jan 1, 1920, to June 1, 1921, I find that of 210 titles no less than 30 per cent are devoted to acute and chronic empyema, 15 per cent to gunshot or other wounds of the chest, including foreign bodies, and 10 per cent to surgical and artificial pneumothorax, though this subject is dealt with, directly or indirectly, in nearly all the papers on intrathoracic surgery as a correlated subject. The remaining 45 per cent are represented unevenly in smaller percentages by foreign bodies in the chest, including the lungs, pleura and mediastinum, in the heart, pericardium, diaphragm, as well as mediastinal abscess, tumors and cysts, including hydatids and dermoids, lung abscess, bronchial fistula, retrosternal goiter and thymus, and in the surgical affections of the chest wall.

This cursory inventory, imperfect as it is, shows that the great war topics, empyema, gunshot wounds of the chest, and pneumothorax, continue to be the dominant topics of discussion, though I believe that a careful statistical compilation of the bibliography, beginning with

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\* President's address, read before the fourth annual meeting of the American Association for Thoracic Surgery, Boston, June 6, 1921

1915, will show that the crest of the wave of thoracic war literature was reached in 1920 and that from now on we may expect a steady decline of the war contributions, which are devoted largely to narratives of individual or collective, but sectional, military experience at the various battle fronts or base hospitals. While the history of the war in its large statistical aspects from the international point of view and from official sources is largely in the making, many of the later publications at home and abroad suggest that with the return of peace we are beginning to view with greater calm and discrimination the lessons of the great war and appraising them at their just valuation. We are now entering a period of transition, in which, with a better perspective, we are utilizing the facts gathered in the strain and tumult of war to the greater profit of the more reflective and deliberate conditions of civilian practice. Many of the sweeping generalizations which at first seemed to wipe out at one stroke all the traditions and teachings of thoracic surgery, so laboriously accumulated by past generations, are being tempered by a more guarded judgment. This does not mean that the experience of the great war has not brought with it great and truly epochal revelations, or that the experience of the war has not left behind it many and momentous truths which will remain as permanent acquisitions in the line of advance and surgical progress—far from it. What I mean is merely that we are now settling into a more reflective and retrospective mood, and learning to differentiate between the urgent and hastily improvised conditions of warfare and the requirements of a calm and better organized civilian practice.

The fearful experience of the pandemic wave of influenzal pneumonia, with its secondary empyemas, which swept, as a deadly plague, over our military camps at home and during the fated years of 1917 and 1918, taught us the most costly and yet the most profitable lesson. We learned then that the deadly *Streptococcus hemolyticus* was not to be dealt with as we had been in the habit of treating the more familiar and less deadly pneumococcus of the metapneumonic pleural infections. It taught us a lesson of caution and conservatism in the treatment of pleural effusions in a way that entirely upset our older notions of pleural drainage. The terrific mortality that attended the free and easy methods of pleural drainage when applied to the epidemic type of acute pneumonic empyema opened our eyes to the dangers of pneumothorax as an added complication to our interventions which extinguished the already crippled function of an acutely inflamed lung.

The resurrection of the closed methods of drainage which obviate the risks of pneumothorax in the acute pneumonic empyemas of streptococcal type—following as it did upon the systematic and collective investigation of the causes of mortality in the military training camps by the Empyema Commission appointed by the Surgeon General of the Army in 1918—was a revelation, and marks an epoch in the history



of empyema which will remain as one of the most creditable and enduring contributions of American medicine to the surgery of the chest

It is curious, but not strange, that in surgery, as in all else, long forgotten or neglected practices, born often of pure instinct and empiricism, are revived, justified, and vindicated in the light of advancing investigation, knowledge and experience. It might thus appear that we have gone back nearly half a century in returning to the closed methods of drainage and aspiration which had their origin in Dieulafoy, Bowditch and Potain, long before Bulau (1891) advocated them—in the minds of the old surgeons who instinctively feared the entrance of air into the chest as a mysterious, but positive evil, without any rational understanding of its dangers apart from the mere teachings of experience.

The same thought is suggested by the peremptory order to close immediately a "sucking wound" (traumatopnea) of the chest, which was mandatory along the whole battle front in France as the first aid treatment to be applied in such cases. This command recalls the antiquity of this practice which was attributed to Richerand in the seventeenth century, and later, in the Napoleonic wars, to Lairey. But the soundness of this teaching was understood long before them, if we may trust the chronicles of the medieval surgeons by the evidence furnished in the old *Chirurgie* of Guy de Chauliac and *Maitre Ambroise Pare*, who insisted that in penetrating wounds of the chest the first step to be taken was to seal immediately the external thoracic opening to prevent the further entrance of air.

This return to the ancient practices, however, does not mean a retrogression, it simply means that the teachings and practices which have alternately prevailed and been discarded by different generations have all had some elements of truth ingrained in them. They have served a useful purpose, but have often fallen into disrepute through abuse of application and erroneous and misguided interpretations because the times were not ripe for them. So we find that the practice of tapping and aspirating acute empyemas, or treating them by closed drainage has gone through many vicissitudes, and after periods of alternating prestige and decadence, has at last come to its just valuation through a clearer and more enlightened appreciation of its precise indications and limitations.

By the side of the more conservative retrenchment in the surgical interventions which characterized the antebellum surgery of empyema, the war has taught us a lesson in the opposite direction, namely, the possibility of controlling a bleeding wound in the lung and arresting a recurrent hemothorax by direct ligation or suture through an open thoracotomy, with far greater success than we had ever dreamt of. Again, we have learned the advantage and practicability of forestalling the dangers of intrathoracic infections before these have had time to

become established. This is well exemplified by the success which has attended the application of the principle of debridement or the primary surgical cleansing of wounds—to the immediate or early extraction of contaminated projectiles whether retained in the lungs, pleura, mediastinum, heart or pericardium. But, in addition, the seeming freedom with which the chest has been opened with total disregard of the once dreaded pneumothorax, or, as Dr Meyer would put it, the “acute operative collapse of the lungs,” long after the patient has recovered from the primary effects of the trauma and the normal relations of the pleura have been restored, is most impressive. Granting that in these post-traumatic states the wounded pleura and lung have been prepared for the pneumothorax which follows the operative procedure, and that the conditions are not identical with those which obtain in the “virgin pleura” or in the patient who has never before been subjected to the shock of a traumatizing transpleural operation, it is none the less true that the success which has attended the intrathoracic operations of the French, and the allied surgeons who have followed them, has opened a new chapter in the military surgery of the chest which furnishes abundant food for reflection.

It is, indeed, the seeming freedom and impunity with which the military surgeons have invaded the chest and manipulated the intrathoracic organs in extracting fragments and foreign bodies that is, perhaps, the most dramatic, if not revolutionizing, of the surgical experiences of the war. Here, the advance of modern roentgenology combined with a daring operative technic has threatened to make a clean sweep—a veritable *tabula rasa*—of all the facts and theories that we so elaborately built up as the very foundation of thoracic surgery.

It is upon the relations of this military experience to pneumothorax and its influence upon civilian practice, which were so admirably presented by my distinguished predecessor in his presidential address, that the storm center of controversy has raged most passionately since the unaided “open door” policy in thoracic surgery has been loudly proclaimed as the surgical doctrine to be followed by the up-to-date surgeon. It would seem incredible that such an absolute and flat denial of all our antebellum experiences in the surgery of the thorax could be possible. It does not seem possible, even now, that all the facts, all the clinical and experimental observations which had been so laboriously gathered from remote antiquity to the embattled years following the fated August of 1914 were all an illusion and a myth.

#### HISTORICAL REVIEW

In 1898 and 1899, nearly a quarter of a century ago, I was impressed and convinced that the dangers of acute pneumothorax were the impediment and bar to the progress of thoracic surgery. I then wrote “Until the dangers of seriously interfering with the respiratory function by

inducing acute collapse of the lungs, is clearly eliminated or reduced to a safe minimum, the analogy between the pleura and peritoneum from the surgical point of view will never exist "

Under the stimulus of this conviction in 1898, I thought and labored to overcome this seemingly insurmountable obstacle to the advance of thoracic surgery. Beginning then with a modification of the Fell-O'Dwyer intraglottic cannula and insufflating bellows which permitted the simultaneous administration of ether vapor—this simple apparatus, which hitherto had been used exclusively as an aid to artificial respiration in the treatment of asphyxia from suffocating gases, drowning, opium narcosis and other nonsurgical conditions, was then transformed into positive pressure apparatus and adapted to the requirements of thoracic operations. But I had no favorable opportunity to try this apparatus in surgical practice on human beings. None the less, I felt so confident of its value and in the principle which it carried with it, that I made "Pulmonary Insufflation with a Modified Fell-O'Dwyer Apparatus in Its Application to Intrathoracic Surgery" the main subject of my address as chairman of the surgical section of the Louisiana State Medical Society, in May, 1898.

Fortunately, the suggestion then made fell on fertile soil and within a year after the reading of this paper, my friend and colleague, Dr. Parham, had occasion to demonstrate the practicability and efficiency of the apparatus in a very difficult but successful case of transpleural resection of the chest wall for sarcoma, which he performed at the Charity Hospital with the original Fell-O'Dwyer apparatus manipulated by Dr. J. D. Bloom, who was then house surgeon, and who was most skilful in its application. This case served as a text for Parham's learned and exhaustive monograph on "Thoracic Resection of Tumors Growing from the Bony Wall of the Chest," which has since remained one of the outstanding landmarks in the literature of the subject.

Simple, and apparently efficient, as the modified Fell-O'Dwyer apparatus seemed to be for warding off the effect of collapse of the lungs in intrapleural operations, I realized, in 1898, that this phase of thoracic surgery was still in its infancy and that the clinical application of intralaryngeal insufflation in thoracic operations was, to a large extent, empiric and justified further experimentation with a view to elevating this mode of treatment to a higher plane of safety and scientific accuracy. I, therefore, planned an entirely new apparatus based upon the pneumatic pump which, after the construction of several models and many trials, finally materialized in the finished working model which I presented to the American Surgical Association in May, 1901. In making this apparatus I had the collaboration of my then assistant and present associate, Dr. John Smyth, whose early training as a mechanical and civil engineer proved of inestimable advantage, hence, it is still catalogued by the manufacturers (McDermott Surgical Co., New Orleans) as the "Matas-Smyth Pump" for artificial respiration in medical and surgical practice. I need not detain you with the details of the appliance which has been fully described elsewhere. Suffice it to say that with the aid of this pump, Dr. Smyth and I were able to study the effects of differential pressure by direct intralaryngeal insufflation on the lungs of dogs and on human cadavers with an accurate gage in the piston stroke and perfect control of the volume of air injected and a manometric record of the plus and minus variations in the pulmonary tract, thus permitting us to determine with accuracy the volume of air required to obtain inflation of the lung in open pneumothorax within physiologic limits, we then confirmed the observation of the physiologists Landois, Donders and Hallion, that a plus

pressure of from 6 to 10 mm and usually of 8 mm Hg was quite sufficient to overcome the elastic retractility of the human lung when collapsed by the admission of air into the pleura. We also determined the extent of the traumatizing or pathologic effects on the lung when the plus pressure was carried to excess as often happened when the bellows were used in the closed chest for artificial respiration in cases of asphyxia from suffocation, drowning, or opium narcosis and other nonsurgical conditions.

It was again with the help of this pump that in 1910 and 1911 with the invaluable collaboration of my then assistant and present associate, Dr C W Allen, who took charge of the laboratory work, we were able to conduct an extensive experimental investigation on the practicability of reducing the caliber of the thoracic aorta and of obliterating its lumen by plicating or infolding its walls by means of a parietal suture applied in two or more stages. The object of these experiments was to constrict the aorta by gradual occlusion as a possible cure for thoracic and high abdominal aneurysms. In these operations, which were all performed on dogs, the thorax was opened freely in the fourth left interspace by a long intercostal incision (Mikulicz-Spangaro) which was enlarged with a self-retaining rib spreader, giving a clear view of the heart, thoracic aorta, and the roots of the lungs, making sufficient room for the necessary exposure and manipulation of the aorta.

Through this large opening, air at once entered the pleura freely, a partial collapse of the lung following the pneumothorax, but the ventilation of the lung was kept up by intralaryngeal insufflation through a soft rubber catheter in the trachea introduced by the glottic route. This was attached to the pump which also supplied the anesthetic vapor and furnished the supply of air entering the lung. The supply of air was regulated to a nicety with the pump and the effect of the plus pressure in inflating the lung was made visible through a large opening in the chest as well as by the manometer. The aortic arch was easily isolated and brought to the surface by a tape which held it as a traction loop, steadying it and controlling the blood stream flowing through the artery while the plicating suturing was in progress. Before this was attempted, however, the effect of the aortic constriction on the heart caused by traction on the loop was carefully studied, as the behavior of the heart in the face of this obstruction helped to determine the degree of constriction in the aorta that the heart could tolerate with safety. When the plication had been completed and the desired constriction obtained, the plus pressure in the pulmonary tract was increased sufficiently to distend the lungs and obliterate the pleura, after which the intercostal incision was closed hermetically.

In our later work we found it practicable to use a foot bellows attached to the intralaryngeal catheter for ventilating the lungs on the Meltzer-Auer principle as we could watch the effect of the air pressure on the lung through the open window in the chest and regulate it accordingly without the need of an additional assistant to record the excursions of the manometer or adjust the gage on the pump.

Without entering into details of this long and laborious research,<sup>1</sup> a full report of which was published in the Transactions of the American Surgical Association for 1913, as these would be irrelevant to the purpose of the present discussion, I would merely state that, as a result of our experience<sup>2</sup> the free

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1 This research lasted from May, 1910, to May, 1913, during which time 151 dogs were used.

2 Matas, Rudolph, and Allen C W. *Ann Surg* 58 304 (Sept) 1913.

opening of the thorax, which was made necessary for the safe manipulation of the aorta was not attended by any mortality or untoward signs or symptoms due to pneumothorax, as the respiration and collapse of the lung was always controlled by the pump. Postoperative infection of the pleura did occur and proved fatal in a little more than 9 per cent of the animals. These operations conclusively demonstrated to our minds the importance of keeping up the ventilation of the lungs and emphasized the value of differential pressure in restoring the normal expansion of the lungs at the close of the operation when the persistence of pneumothorax with a complete or partial atelectasis is more likely to be followed by profuse serous effusion than when the pleura is promptly filled by the expanded lung. Whatever may be said of the tolerance of human lungs to acute surgical atelectasis or of the pleura to pneumothorax, it certainly cannot be denied that differential pressure is an obligate adjunct to the technic of intrathoracic operations in dogs for in these, as every experimenter knows, the frequent intercommunication of the pleurae leads to a bilateral pneumothorax which often proves fatal at the very outset of a unilateral thoracotomy.

The decade 1900 to 1910, witnessed an extraordinary awakening to the possibilities of thoracic surgery and the literature teemed with the reports of new inventions and devices which clustered around and about the two opposite principles of differential pressure—the one typified by the *minus* pressure chamber of Sauerbruch (1904) and the other by the *plus* pressure apparatus of Brauer (1904)—all of these finally culminating in a single and highly perfected apparatus which combined both principles and could alternately apply the *plus* or *minus* pressure principle, according to the indications in any particular case. This ingenious apparatus we owe to Dr. Meyer (1909) and to his constant and untiring efforts to attain the ideal of safety in intrathoracic interventions.

Then Meltzer and Auer (1909-1910) came a little later to startle us with a discovery of their revolutionizing principle of intratracheal ventilation without rhythmic pulmonary distention, which so simplified the technic of pulmonary aeration in spite of the bilateral collapse of the lung, that we felt that the acme of simplicity and effectiveness had been reached and that the great problem of surgical pneumothorax had been at last solved and made available to every operating surgeon. Those of us who had labored industriously for years to attain what seemed to be a step forward in the advance on the thorax gloried in these achievements which were no longer confined to the narrow enclosure of the animal laboratory, but gave proof of their life saving value in the broader arena of the human clinic as well.

Such was the situation in thoracic surgery when the early reports which had reached us from the seat of war, at the end of 1916, in succeeding years told us of the extraordinary feats that were going on in the battle front in France, where projectiles of all sorts were being extracted in a wholesale fashion from the thoracic organs and with

seeming total disregard of the most elementary precautions against pneumothorax and lung collapse—and yet with a phenomenal and unheard-of success. The story of this extraordinary achievement as told by Pierre Duval, R. LeFort, Depage and their many associates and colleagues serving in the French battle front, and more recently by Sir Berkeley Moynihan, for the British surgeons, is too familiar to all to bear repetition.

It was only last year at the New Orleans meeting of this association that Dr. Meyer in his presidential address on the "Fundamental Principles of Thoracic Surgery" and in the preceding year, at the Atlantic City meeting, and in other publications, has gone over this question most thoroughly, and with his acknowledged competence and authority, has shown the fallacy of accepting as final the conclusions and generalizations based upon the experience on a single phase of the traumatology of the thorax, at least in their application to the entire domain of thoracic surgery.

#### THE PRESENT STATUS OF AIDED AND UNAIDED TRANSPLEURAL SURGERY: A CONTROVERSY AND A DISCUSSION

The facts and the arguments presented by our former president against the unqualified and indiscriminate acceptance of the experiences of the war in regard to the benignity of pneumothorax and the superfluousness and uselessness of all artificial aids to counteract the perilous effects of acute surgical pneumothorax (which we cannot be convinced are imaginary as some would have us believe) have been too recently presented and are too familiar to all the members of this association to justify their repetition. Suffice it to say that I would regard it as a veritable calamity that would befall the progress of thoracic surgery if the experience of the war were to breed a contempt or indifference for the principles and the methods of differential pressure in warding off the perils of acute pneumothorax, or if the old practice of open, "unaided" transpleural thoracotomy were accepted as a generalization, without reserve or very specific restrictions and limitations. I would not trespass upon your indulgence by any further reference to the subject upon which most of us have settled convictions were it not that the present status of the "aided and unaided" transpleural surgery of the thoracic organs has been brought to a very pointed issue by a discussion which took place at the Société de chirurgie of Paris, on the ninth of February of the present year, which was precipitated by a paper on intrathoracic dermoids by MM. Clerc and Pierre Duval in which the latter virtually threw down the gauntlet and challenged the advocates of differential pressure and respiratory aids to show any better, or as good results as he had obtained by the unaided transpleural open pneumothorax method without artificial help of any kind. He referred to the aided

differential pressure method as the "German method" and the unaided method as the "French method." To this I take a serious exception for many reasons which I will consider later, but chiefly because the distinctions which he would establish on a basis of nationality rest on erroneous historic premises and a mistaken conception of the origin of the method which he calls "German."

In his enthusiastic advocacy of the "unaided" as compared with the "aided" or "physiologic methods," Duval contrasts the condition of a patient operated upon by Garre for intrathoracic dermoid cyst of the mediastinum in 1914, in whom the tumor was removed by a transpleural thoracotomy under differential pressure, with the Tiegel apparatus, and his own case which he then reported to the society. He compares the behavior of the two patients during and after the operation, he shows that the pulse, blood pressure, and respiration were far less disturbed in his patient, upon whom he operated purposely without any respiratory aids whatsoever. The patient operated on by Garré recovered after a stormy and protracted convalescence complicated by infection and suppuration, the wound healing only after the end of four months, leaving a hernia of the lung at the site of the thoracotomy, while the wound in his (Duval's) patient healed by first intention without leaving a permanent weakness in the thoracic wall. Recovery had taken place without complication except for a serous effusion of 500 c c, which had yielded after one tapping, with the patient well enough to be up on the ninth day.

On reading the details of these two cases as they are given in Duval's own text, it is not quite clear how he arrives at the conclusion that the prompt healing and recovery of his patient and the protracted convalescence of the other are in any manner ascribable to the fact that Duval operated on his patient without artificial aids to respiration and that in the other case a differential pressure appliance was used to counteract the effects of the pneumothorax. There is no real analogy or parallel that can be fairly established between the two cases, as the conditions that influenced the postoperative course in both had no bearing on the question at issue, namely, the prophylaxis of pneumothorax. While in no way minimizing or detracting from the brilliancy of results obtained by Duval with his technic—a merit to which we have been accustomed by his splendid record of achievements as a thoracic surgeon of unsurpassed experience and superior skill—it does not appear that in drawing a parallel between these two cases he has been fair in throwing all the burden of reproach for the complications and protracted convalescence of Garre's case on the principle and the method of differential pressure adopted by the latter. The two histories as given by Duval show that other elements quite foreign to the question of pneumothorax account for the discrepancies between the two cases. A brief synopsis of the main facts is sufficient to show that the two operations had only two features in common, and that is that both were performed for mediastinal dermoids and that both of these cysts were sufficiently free from blended, dense adhesions to vital parts to permit of their complete extirpation. In both the pleurae were opened wide. In Duval's case only the left pleura, in Garre's

*both right and left* pleurae were opened Garre's patient, ten years older than Duval's, had suffered from dyspnea for six years before the operation, presumably from the encroachment of the cyst on the venae cavae and right side of the heart Duval's patient was a woman who had only recently been disturbed by cardiac palpitation, but who was otherwise sound and in good health One was a right-sided tumor, the other left-sided In Garre's case a large window, requiring a much more severe operation—the resection of four ribs—was made to enable the cyst to be extracted whole In Duval's case only one rib, the fourth, was resected In Garre's case the mediastinal cavity and the extrapleural space were tamponed and a severe infection followed, in Duval's case the wound was sealed hermetically without drainage and there was no infection

The lesson that we gather from all this is that Duval was able to extract a collapsed cyst through one open pleura (left) without accident and complete success in spite of his total disregard of the pneumothorax—something which is fortunate, as it is not *always* that the pleura is opened so happily This success, however, does not detract from the method or the prudence of Garre, who provided against the accidental opening of *both* pleurae (as happened in his case) by operating under differential pressure Furthermore, there is no evidence to show that the use of the differential pressure apparatus in any way complicated or contributed to the gravity of the operation

What we do learn from Garre's experience, as Professor Quenu remarked in the discussion, is that danger lurks in the tampon or pack when left in the wound of a transpleural thoracotomy, and the brilliant results obtained in his (Duval) case are due, apart from his skill in avoiding accidents, to the fortunate enucleability of the cyst and a freedom from dense attachments to its dangerous surroundings, to his economic treatment of the thoracic skeleton which limited the mutilation to the extent of one rib, thus creating a space through which he was able to extract the *collapsed* cyst with a minimum of trauma, and, finally, what is most important, that he was able to close the wound hermetically, leaving no pack or drain to contaminate the bed of the cyst, in this way obtaining a primary healing of the wound and an escape from infection which was the chief cause of the complications in Garre's case In other words, the real cause of the prompt recovery in Duval's case is not, as he suggests, due to the fact that he did not use a differential pressure apparatus, or, to his deliberate disregard of every precaution against the possible dangers of acute pneumothorax, but to the freedom from septic complications, and the minimal trauma which his otherwise excellent technic provided

While it would not seem fair to judge of the merits of the two great operative principles or methods that have been brought in contrast on the basis of so limited an experience, especially when we consider that so many confusing elements, which are foreign to the question of pneumothorax, are injected into the problem, we cannot overlook the fact that Duval has only seized upon this case as a text for a renewal of his former attacks upon the aided methods of transpleural thoracotomy In this instance, he utilized the extirpation of an intrathoracic dermoid to show that the principle of unaided open pneumothorax applies to the nontraumatic surgery of the chest—as this case exemplified—as well as to the purely traumatic in which he has so great an experience and so just an authority



Commenting on a recent statement of Kuttner's, in a chapter on the progress of thoracic surgery, in the well known "Operationslehre" of Bier, Braun and Kummel (1920), "that the surgery of the thoracic organs has made great progress in the last ten years, since we have learned how to overcome the dangers of surgical operative pneumothorax," he is particularly sensitive to, and resents, the additional comment of Kuttner that "French surgeons *still* depend, even now, upon progressive (unaided) pneumothorax, in their largest intrathoracic operations," and practically ignores their recent contributions with scarcely a notice, though Kuttner adds "that their (French) results, however, are well worthy of attention"

Duval says that Kuttner merely voices the general German sentiment in criticizing the French in their attitude toward operative pneumothorax and in regarding as superfluous all measures that tend to prevent the collapse of the lung

Duval objects to the method of differential pressure which he designates as "the German method," saying that it is cumbersome, complicated and superfluous though it appears to be very scientific, and he opposes to it the simple, open, unaided method which he designates as the "French method," in which the pneumothorax is disregarded and lung collapse is actually invited. He affirms that artificial aids to respiration are superfluous, that unilateral surgical pneumothorax is attended with no special risk and that neither the heart nor the opposite lung is disturbed or incommoded by the acute collapse of the lung when these organs are normal or healthy, etc

He contends that the latter method had given proof of its safety and efficiency long before the war in the hands of the French surgeons Bazy, Walther, Delorme, Delageniere, Marion, Poirier, and others too numerous to mention, and that during the war this simple method alone had made possible the magnificent achievements in thoracic surgery which had been accomplished by the French surgeons. He asks "What have the aided methods contributed to the advancement of thoracic surgery by the Germans during the war?"

"I have the conviction," he says, "that the future of intrathoracic surgery when confined to one half of the chest lies in the open unaided method of total pneumothorax. I entertain the conviction that the best state of the lung for all the operations that may be performed upon it or within the thorax is the lung in the collapsed state. The collapsed lung facilitates infinitely more than the inflated lung (under differential pressure) the manipulations and maneuvers that the technic may require. The distended lung is in the way of the operator, it even tends to herniate in the wound, it crowds the field, and it displaces and almost ejects out of the thorax all the means of protection that the aseptic technic requires."

In the discussion that followed the reading of Clerc's and Duval's papers there was a quite general agreement among the members of the society who participated, that *unilateral* as distinguished from *bilateral* pneumothorax was a relatively safe surgical condition in the majority of the cases. They believed that there was some advantage in dealing with the collapsed lung, but the approval of M. Duval's total rejection of the principle and method of differential pressure, especially in operations which might involve the opening of both pleurae, was far from unanimous.

For instance, Tuffier, in speaking of the extirpation of mediastinal dermoids, said, "If the cyst is unilateral, it is amenable, as any other unilateral intrathoracic tumor, to a transpleural dissection through a free opening in the pleura. That is a settled question, a *res adjudicata*," but it would be an exaggeration and even an error to suppress or condemn in an absolute fashion all the apparatus for differential pressure (baronarcose) which are calculated to keep up the respiration when the pleura is opened." He closed by saying that "in the immense majority of cases, a free large opening of the pleura is the best method of extirpation and intervention on the lung and mediastinum, but in certain exceptional cases in which there is risk of opening the two pleurae, it is necessary to have in readiness and to resort to differential pressure. On this point, I protest against the *absolutism* of Clerc's and Duval's conclusions."

I fear I have trespassed upon your indulgence by engaging your attention in a foreign controversy which, notwithstanding its strictly scientific character, is tinged with some of the acrimony engendered by the bitterness of the great conflict from which we have just emerged. But the question brought up by M. Duval at the Societe de chirurgie is one which, as M. Tuffier well stated, involves the whole history and development of intrathoracic transpleural surgery, and as such rises above all personal feelings or national prejudices. As an association organized in the interest of thoracic surgery, it concerns us directly and vitally. Therefore, this seeming digression is justified not only because of its bearings upon our special work, but because it is our duty to seek the truth and disentangle it as dispassionately as possible from the mass of *incumfusa* that encumber it.

To begin with, M. Duval has placed the methods of aided respiration or differential pressure in opposition to the "unaided," by designating the former as the "German," and the latter, as the "French," method. To those of us, who, like myself, have followed assiduously the history of thoracic surgery, before and since what might well be called its renaissance in the middle nineties and who have been nourished and inspired by the great masters of French surgical thought, this distinction would seem most regrettable and unfortunate, because no matter

how much the experience of the war has altered the convictions of M Duval and his associates in regard to the value of the aided or unaided methods of respiration in thoracic surgery, he can scarcely be oblivious of the fact that the methods of differential pressure which he designates as "German" had their origin in France and in the very heart of the society which he was addressing. A quarter of a century has elapsed since Tuffier and Hallion (November, 1896) and Quenu and Longuet (December, 1896) reported the results of their independent, but contemporaneous, experimental investigation of the methods of preventing and counteracting the dangers of acute surgical pneumothorax by creating adhesions and especially by various methods of differential pressure, but I vividly remember the keen interest and enthusiasm then aroused in me by these two epochal contributions. They were, indeed, the seed from which germinated the budding of a new surgery in the decade that followed. Tuffier and Hallion, by utilizing the physiologic methods of the laboratory, gave us an illuminating and impressive insight into what could be accomplished in the exploration and treatment of thoracic lesions by maintaining the functions of the lung with the help of plus pressure by intralaryngeal insufflation, and Quénu and Longuet formulated the principle of differential pressure, and by numerous experiments with compressed air as a continuous *plus* pressure atmosphere, *without insufflation*, opened the way to the methods of hypopressure and hyperpressure, which years after (1904-1906) developed into the atmospheric plus pressure (head chamber) of Brauer and the minus pressure (body) chamber of Sauerbruch. While the importance of these methods as applied to dogs has been denied in unilateral pneumothorax in man, the fact remains that they are the corner stone of the foundation upon which the vast superstructure of modern intra-thoracic surgery and its ancillary branches has been built. And this fact is fully admitted by the Germans themselves.<sup>3</sup>

It is, therefore, not surprising that M. Tuffier who opened the discussion should have protested "against the absolutism of the conclusions of MM. Clerc and Duval", nor, could it be expected that M. Quénu, who had contributed so largely and so ably to illuminate the problems of pneumothorax, should remain silent or fail to remind the society (as he did very briefly but pointedly) that "the idea of hyperpressure and hypopressure in its application to thoracic surgery was born here, in France, and not in Germany, and Tuffier and I conceived it at the same time."

Furthermore, it would also seem unfair to exclude, by the specific label "German," all the workers of other nationalities who have contributed so laboriously to the study and elaboration of this originally

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<sup>3</sup> Garre, C., and Quincke. *Surgery of the Lungs*, Ed. 2, Jena, Gustav Fischer, 1912.

French conception long before the Germans took it up on their own account and made it, with their characteristic enterprise, the object of their special culture. I must confess to a special personal interest in this phase of the question, because as a pioneer worker in this field at a time (1897) when even the term "differential pressure" had not yet found its application in the surgical vocabulary, I had occasion to inquire into "the history of the methods of intralaryngeal insufflation for the relief of acute surgical pneumothorax." As the result of my investigation, which appeared in several publications,<sup>4</sup> I learned that the names of Pean, Tuffier and Hallion, Quenu and Longuet, and Doyen, of Paris, Lambotte and Wolliez, of Brussels, and<sup>5</sup> H. Milton of Cairo stood foremost in the list of historic pioneers who first conceived and applied the idea of differential pressure for the relief of surgical pneumothorax. Pean, Lambotte, Tuffier and Doyen and Milton operated on the human subject. Apropos of Milton I am reminded that after experimenting successfully on goats with the tracheal insufflation for the relief of traumatic pneumothorax, he operated on an Egyptian fellah who had extensive tuberculosis of the sternum and mediastinal glands. He sawed the sternum in half by median incision and by spreading the two halves obtained a wide opening of the mediastinal space which permitted an easy exposure and manipulation of the trachea and of the vessels at the root of the heart, the innominate, pericardium, bronchi, lungs and pleurae. This operation is the parent of the various midsternal thoracotomies of which the Duval-Barastý "median thoraco-abdominal-pericardiectomy" which I described at the New Orleans meeting of this association in July, 1920, is the perfected type. Milton's experiments on the goat had led him to fear the dangers of pneumothorax and for this reason he performed this operation (for the first time in human surgery) under the protection of tracheal insufflation (*plus* pressure) anesthesia, and saved his patient. Duval, also, by his notable modification of this procedure, succeeded, in 1918, in extracting a moving projectile from the inferior vena cava at its junction with the heart and thereby achieved one of the most brilliant and unique exploits recorded in thoracic surgery. He did not resort to pulmonary insufflation or differential aids, but in describing his operation, he<sup>5</sup> lays stress on the *advantage* of his mediosternal section over the lateral transpleural thoracotomies, from the fact that by a median incision the pleura is avoided, proving by this that, notwithstanding his confidence in the transpleural methods which he advocates so vigorously, he still regards pneumothorax as an undesirable complication to be avoided when possible.

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4 Matas Rudolph Tr Louisiana State M Soc, May 10, 1898 Ann Surg 29 409, 1899, Intralaryngeal Insufflation J A M A 34 1371 (June 2) 1900 con'd ibid 34 1468 (June 9) 1900 Tr Am Surg Assn May 1901

5 Duval, P Presse med 26 437 (Aug 29) 1918

RESPIRATORY 'AIDS' AND METHODS OF OVERCOMING THE EFFECTS  
OF COLLAPSE OF THE LUNGS, GREATLY SIMPLIFIED

Resuming the historical phase of this question, we find that if we add my several contributions (1898-1901) and those of F W Parham and J B Murphy (1898) to those of the initial period in the history of *aided* transpleural surgery, as American contributions, we will have grouped together a series of closely related experimental and clinical facts and deductions which, originating in France, Belgium, Great Britain and America at the close of the last century, gave the signal and actual start to the international race for the systematic and scientific invasion of the thorax which characterized the decade that followed

It was not until 1904 that under the stimulus and encouragement of Mikulicz who was then especially concerned with a safe mode of approach to the thoracic esophagus, Sauerbruch and Brauer independently invented their plus and minus appliances based upon the principles of differential atmospheric pressure as distinguished from rhythmic pulmonary insufflation which had been utilized by the previous operators, except Pean, Wolliez and Quenu, up to that time. Coincidentally with the innovations of Sauerbruch and Brauer, F Kuhn of Cassel (1904) had elaborated the simple method of direct intralaryngeal insufflation which I had first suggested and applied in New Orleans with the Fell-O'Dwyer apparatus, in 1889. In this way three distinct methods of overcoming the collapse of the lungs came in vogue, which led to a great variety and complexity of apparatus. These multiplied with prodigious rapidity in Germany and spread thence to every important surgical clinic of the world. You are too familiar with the history of this great movement, which at one time overran the literature with its feverish activity, to warrant my detaining you with any detailed account of its progress. Suffice it to say that in an endeavor to improve and perfect these auxiliaries to respiration, a large body of important new data on the mechanics, physics, physiology and anatomy of the respiratory organs and function rapidly accumulated which have remained as enduring acquisitions to thoracic surgery.

While Germany was the greatest center of activity during this period, the workers of other nations were no laggards in the race. In Belgium the original laryngeal intubation and insufflation of Lambotte, and the Spirophore of Wolliez for negative pressure (which had suggested the negative pressure chamber of Sauerbruch) were succeeded by the apparatus of Mayer and Darnis, while Depage and Willems were experimenting with this and other models. In France, Doyen designed an entirely new plus pressure apparatus which had supplanted his original compound bellows of 1896. Vidal and Pierre Delbet had

added new and ingenious plus pressure appliances, while Tuffier was indefatigable in trying and comparing the most important foreign models in his clinic at Beaujon. Débayre, Gosset and Guibal were also busy with others, discussing the pros and cons of the new methods. In the United States, where every new thought and every improvement that may contribute to the advancement of surgery by adding to the safety of its methods and by expanding its practical usefulness is welcomed, many progressive surgeons instantly seized with avidity, and put to the test of experiment and actual clinical experience, the new inventions which had found a practical expression in Germany. The mere mention of the names of Samuel Robinson, F. T. Murphy, of Boston; Willy Meyer, Nathan Green, H. H. Janeway, Draper Maury, of New York; Willard, Dorrance, Babcock, of Philadelphia; J. B. Murphy, Chicago; Crile and Sollmann, of Cleveland; Dudley Tait, of San Francisco, and Matas, Parham, Smyth and Allen, of New Orleans, recalled at this moment, among others too numerous to mention, suffice to show the wide interest felt in this subject throughout the country. Many here present remember the memorable symposium on surgical pneumothorax at the meeting of the surgical section of the American Medical Association at Chicago, 1908, at which I had the honor to preside and in which Sauerbruch himself led the discussion by demonstrating his negative pressure chamber, with J. B. Murphy, Willy Meyer, Crile, Samuel Robinson, Green, Janeway, and Maury, as prominent participants and can tell how earnestly and liberally the surgeons of this country shared in the world-wide interest roused by this new phase of thoracic surgery.

But in 1910, a new note was heard which rose out of this great bustle of activity, when Meltzer and Auer by their experiments at the Rockefeller Institute demonstrated the simplicity and security afforded by their new principle of pulmonary ventilation by continuous intratracheal insufflation, without respiratory movements or rhythmic dilatation of the lungs. Though the discovery of this revolutionizing principle had been foreshadowed by Volhard and Kuhn (1905) in Germany and Sollmann and Robinson in this country (1907-1908), the demonstrations given by Meltzer, Carrel and Elsberg at the Rockefeller Institute created a profound impression which soon echoed all over the surgical world.

Between 1910 and 1914 the literature was again flooded with descriptions of new appliances, apparatus, experiments and discussions which were contributed not only by surgeons but by professional anesthetists who had become deeply interested in the anesthetic side of insufflation as a part of their own province. Improved models and methods for meeting the double requirements of anesthesia and respiration were brought out by Elsberg, Boothby and Cotton, Robinson

Quimby, Ehrenfried, J R Rogers, Pratt, Gwathmey, and especially by H H Janeway, and others too numerous to mention, in this country alone. These inventions gave a permanent stability to the principle of differential pressure by continuous insufflation and greatly simplified and extended its application.

With the advent of the Meltzer and Auer method in 1910, it may be said that the mechanical ingenuity and inventiveness which had been previously displayed in developing the expensive, complex and fixed apparatus of the so-called cabinet type, began to lag and the technic of thoracic surgery entered into another phase in which pulmonary ventilation with compressed air or oxygen delivered from bellows, tanks, or by electric motors, into the trachea by intralaryngeal or nasopharyngeal insufflation, or, more often, by simple, close fitting masks, rapidly supplanted the more complex methods of differential pressure. These simple portable methods which Dr Robinson has so long advocated can now be easily made a part of any of the several gas-ether-oxygen sequence anesthetic outfits that are in common use in any of the clinics of the country where an intrathoracic transpleural operation, such as we have in view, is likely to be undertaken.

We have now reached a stage in the evolution of our methods of pneumothorax prophylaxis in thoracic surgery against which the objections raised by M Duval and his followers are no longer valid. The methods that we employ today are not complex, cumbersome or expensive, they are virtually a part of the anesthetic outfits wherever a modern gas-ether-oxygen sequence apparatus is used, which is almost equivalent to saying that it is an adjunct to any well equipped operating room in this country. And the argument upon which so much stress has been laid, that these aids to respiration interfere with the collapse of the lung, a condition that is so advantageous for the operations of intrathoracic surgery, no longer holds good in the presence of the simple methods of tracheal, or intrapharyngeal, aeration in which the lung is held practically flat and still, and is only inflated as desired at the close of the intervention when the lung is allowed to fill the pleura.<sup>6</sup>

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6 Dr Howard Lilienthal of New York, in relating his experiences with anesthesia in thoracic surgery in the war zone, at the Symposium of the American Association of Anesthetists, Atlantic City, N J, June 9-10, 1919 (*J A M A* **73** 444 [Aug 9] 1919), relates how an apparatus of elementary simplicity was improvised by which ether anesthesia and the continuous ventilation of the lung could be maintained by providing a flow of air, preferably from a foot bellows to pass through an ether container, in varying quantity, to be carried to the patient's pharynx by means of a nasal tube or catheter, after a preliminary ether anesthesia in the usual way. "At first it was doubted that endopharyngeal insufflation would suffice for intrathoracic surgery, but it was soon found that the amount of pressure that could be maintained within the pharynx was quite sufficient to keep the

THE NEED AND VALUE OF ARTIFICIAL AIDS TO RESPIRATION  
SUSTAINED

And now that we have disposed of these collateral objections let us take up the real question at issue Are the artificial aids to respiration in acute open surgical pneumothorax really necessary or advantageous as a measure of safety and protection to the patient? Are the fears we have entertained and the accidents against which we have labored so intensely and industriously in the last quarter of a century, a mere fancy, an illusion and a myth? The mere statement of such a question would imply a doubt that is incompatible with the accumulated testimony of succeeding generations of surgeons whose records of catastrophes and narrow escapes have given dramatic thrills to so many episodes in the history of thoracic surgery

Nor is such a sweeping denial of the value of the mechanical aids to respiration and operative pneumothorax, as has been indulged in by the partisans of unaided transpleural surgery, compatible with the opinion that the dangers and accidents that lurk in the pleura are imaginary and chimerical when the operations are limited to only one side of the thorax

Even M Duval has rectified his position by admitting in a later communication that in every thoracic operation that risked the opening of both pleurae differential pressure would be necessary This admission suggests that at least some progress has been accomplished by the methods of differential pressure

The controversy is, therefore, limited to *unilateral* pneumothorax which he contends is so innocent and benign in its effects that it should be considered an advantage rather than a complication Let us now inquire into this benignity, upon which the disregard of all respiratory aids is based and on account of which we are advised to return to the old unguarded methods of open thoracotomy

In 1898 Quenu and Longuet,<sup>7</sup> after an alarming personal experience in thoracotomy, carefully investigated the phenomena of acute pneumo-

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lungs in any state of inflation desired This was the method of pharyngeal insufflation anesthesia which he has adopted and has applied so successfully in his recent and notable case of intrathoracic-transpleural resection for carcinoma of the esophagus (Proc Am Surg Assn, Toronto, June, 1921) In my thoracic practice and in operations of the face and mouth, I have depended for some time exclusively upon the continuous insufflation of the pharynx with a stream of gas-oxygen (with or without ether) delivered under regulated pressure from the tank of a McKesson (Toledo, Ohio) anesthesia apparatus in the hands of my expert anesthetist Dr Caine In many thoracic cases a tightly fitting gas mask will suffice, but the continuous ventilation of the pharynx through a nasal catheter is so simple and satisfactory that the intratracheal method is now rarely used

<sup>7</sup> Quenu and Longuet Rev de chir 18 1898



thorax as they had been observed in transpleural operations for the resection of tumors of the thoracic skeleton. They collected and tabulated all the available cases recorded in the literature and classified them into three groups: (1) cases marked by little or no disturbance when the pleura was opened, (2) cases presenting only moderate disturbances, (3) cases showing quite stormy manifestations and threatening life. This classification was adopted by Parham (1898), who added his own and other cases to the list, giving one allotment of sixteen for the first group, ten to the second, and fifteen to the third. There were in all forty-one cases in which operation was performed and in which more than 60 per cent showed some symptoms, of which 36 per cent were alarming and critical. Gerulanos' statistics published at the same time (October, 1898) yielded the same conclusion and conveyed the same impression (nearly 31 per cent of alarming cases). All but Parham's second case, in which respiratory and circulatory disturbances were promptly relieved by insufflation with the Fell-O'Dwyer apparatus, were *unilateral* thoracotomies performed before the days when artificial pressure or respiratory aids had come into surgery. These thoracotomies were performed in the atypical way required by parietal tumors, and intentionally or accidentally caused an open pneumothorax with complete or partial collapse of the lung. The technic was in effect, and, so far as the pneumothorax was concerned, identical with the free and open practice which M. Duval designates as the "French" method, but which in reality has no claim to any national distinction since it was the only procedure available to surgeons and was the universal practice, as a procedure of necessity. Yet it is with this procedure, beginning in 1818 with the classic case of Richerand, that the traditionally evil reputation of operative pneumothorax with the collapse of the nonadherent lung is so tenaciously associated. And it is in this type of unilateral pneumothorax that the various emergency devices for the relief of the alarming and critical manifestations exhibited by more than 36 per cent of these cases originated. If the acute collapse of the lung caused by the surgical opening of the pleura is so benign that it is now not only disregarded, but is actually invited (Duval, LeFort et al.), why have so many operators been compelled to interrupt hurriedly their operations by immediately closing the external opening with the first expedient that came to hand—the operator's hands, a towel, gauze packs, the nearest skin or muscle flaps, or by hermetically suturing the wound? It is in this way that the practice of making traction on the lung and anchoring it to the opening in the chest to obturate it, or to suture it to the parietes originated and for which the picturesque word *amarrage* is now classical in French texts, and the more pretentious term of costopneumopexy was devised. Again others in similar distress, like Witzel, have found relief in filling the pleura with water or temporarily

steadying the mediastinum with forceps until the pleura could be closed. Why did Lawson and Dollinger make it a practice to create a preliminary "preparatory" pneumothorax by injecting air into the pleura on the eve of a transpleural thoracotomy and why did Tuffier prefer an *extrapleural décollement* in order to excise the apex of a tuberculous lung so many years ago, and how did the *arrière point* of Roux originate, and so many other means and measures which were advocated twenty-five years ago to create adhesions? The fear of pneumothorax limited Bazy's early attempts at exploration (1895) to an opening which barely admitted the finger, "*boutonnière exploratrice*"

Even Delangeniere, who in 1902 advocated the exploration of the pleura by transpleural thoracotomy without any preliminary precautions, was very cautious in advising his special technic which would allow the gradual entrance of air and which provided a flap which would permit immediate closure of the opening in the event that alarming symptoms should occur in the course of the exploration. And now we are told, in complete reversal of all the old teachings, that the larger the opening and the more free the pneumothorax the safer the thoracotomy. Of course, it will be said that all this is ancient history and that the great fear of the pleura is analogous to that dread of the peritoneum which for so many centuries barred entrance to the abdomen. But the analogy is not the same, for when the aseptic key came to our possession the lock of the abdomen quickly yielded and surrendered all its mysteries, but asepsis has not opened the gates of the thorax so widely, and they still creak on their hinges when we pry them open. While admitting that pneumothorax is by no means the only impediment to the surgical mastery of the thorax, the analogy between the pleura and the peritoneum fails in the presence of the incontrovertible testimony of surgical history and experience that in a certain undetermined percentage of transpleural thoracotomies, the mere act of opening the pleura followed by the collapse of the lung, has proved profoundly disturbing and even fatal. No one denies that innumerable transpleural thoracotomies have been, and are being, successfully performed with the lung in complete collapse. That is being done every day in the routine of surgical treatment of the pathologic pleura which has been immunized by preexisting trauma, infection or disease.

Every one knows that a large percentage of patients with thoracic disturbances that come to us for operation tolerate intrapleural and pulmonary and operative procedures with relative impunity or with such transitory disturbances that the pneumothorax per se can scarcely be regarded as a complication. This has been universally admitted even by those who are most prominently identified with the advocacy and practice of differential pressure. For example Garre<sup>8</sup> who is so

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8 Garre and Quincke Footnote 3

severely criticized by Duval, states, in his "Surgery of the Lung," that he has performed the greater number of his operations on the lung without any auxiliary apparatus and reserves the artificial appliances for certain operations in which, apart from a bilateral invasion of the pleurae, he regards them as indispensable. There is quite a leap between this attitude and a denial of all risk in unilateral pneumothorax. It does not mean that the normal nonadherent pleura can be opened freely and sufficiently to explore thoroughly and manipulate the thoracic contents with impunity, or that accidents never happen, or, that when they do happen it is so rare an occurrence that they may be regarded as a negligible quantity in the problem.

M. Duval bases his changed attitude toward differential pressure aids to his war experience. Indeed, no one has greater reason to be proud of his record in the surgical treatment of war wounds of the chest. No surgeon who has read his fascinating book on "The War Wounds of the Lung" which has immortalized the achievements of the French Auto-chirurgicale, No. 21, while serving with the allied armies at the Somme, can fail to admire the daring and the skill which he displayed in dealing with the bleeding wounds of the lungs and in the extraction of contaminated projectiles by approaching them systematically through a free and open thoracotomy. Through his surgical leadership, French surgery can be credited with the initiative in lifting the military surgery of the lung for trauma, from the bed of unapproachable exclusiveness, in which it had been lying before the war, to a plane of actual practical efficiency which had been denied it or kindly conceded before this time.<sup>9</sup>

But the success of the open transpleural operation in the emergencies of war, when applied to a bleeding lung compressed by a vast hemothorax or a traumatic pneumothorax, does not necessarily prove the benign character of acute pneumothorax when the normal, uninjured pleura is opened, and acute collapse of the lung is deliberately induced as a preliminary to an intrathoracic operation. Neither does the delayed extraction of retained projectiles in the lung or mediastinum signify—no matter with what success this may be accomplished—that the operation is without risk or danger from the collapse per se. Even here we find that the experience of the war surgeons was divided on the importance attached to the free opening of the pleura. Surely there is a great difference in this regard when we compare the technic

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9 To visualize the transformed attitude of surgery toward the traumatism of the chest, compare the experiences related in Duval's "Surgery of the Lung" (1918) with the conservative views expressed, with characteristic eloquence, by Reclus at the French Congress of Surgery in 1895 (Paget, Stephen Surgery of the Chest, 1896, p. 443).

of Pettit de LaVilleon who, through a small thoracic incision (barely large enough to admit the narrow blades of a forceps), penetrates the chest in search of the retained missile, and that of the operators who attack the problem through a large open fenestra. It would seem that in avoiding an open pneumothorax by this cautious incision, de LaVilleon, whose experience outclasses in numbers and success all other competitors in this field, regarded the free opening of the pleura as an added complication. But to come closer to the present discussion, did not Okinczyc state in the debate at the Societe de chirurgie, following the reading of Duval's paper, that while he recognized the "habitual innocuousness" of operative pneumothorax and agreed that it greatly simplified intrathoracic surgery, as he had practiced it during the war, he, nevertheless, had seen very serious accidents happen which he did not attribute to the entrance of air into the pleura but to a reflex syncope of mediastinal origin which followed upon contraction of the collapsed lung. A patient died under his eye from syncope at the very moment that he was maneuvering to exteriorize the lung. The interpretation of this occurrence would have seemed doubtful if he had not seen the same fatal accident occur in the hands of one of his assistants, in two other cases, and at the precise moment when traction was made on the lung to exteriorize it.

On the other hand, M. Quenu promptly rose to disagree with Okinczyc in believing that syncopal accidents which occur after the opening of the pleura are due solely to the displacement and traction of the lung. "I once witnessed," he said, "a sudden death following a simple puncture of the pleura with the needle of the Potain aspirator, by a colleague, who, by mistake, had injected air into the pleural cavity instead of aspirating it."

And in this we see the seeming contradictions of experience. On the one hand, traction on the collapsed lung has been long held as one of the surest ways of relieving the asphyxial and syncopal phenomena of pneumothorax, and on the other, instant death seems to have followed this procedure. Thus, another lesson is taught to the profit of caution in accepting sweeping generalizations based on the contradictory facts of experience.

Those who entertain any doubts as to the reality of the accidents of all degrees of gravity, including many deaths which may follow the intentional creation of an artificial pneumothorax will do well to read the recent exhaustive review of the evidence collected by Dr. Karl Schlaepfer,<sup>10</sup> formerly of Zurich, now of Baltimore. While this essay deals chiefly with the accidents which follow the induction of closed artificial pneumothorax for therapeutic purposes the nature of these accidents

10 Schlaepfer, Karl. *Ergebn d Chir u Orthop* **14** 1921

and the manner of their occurrence have a direct bearing upon the untoward effects that have been so frequently observed in transpleural operations

What we have learned with a wider and increasing thoracic experience in the last twenty years, and especially since the war, is that the number of patients who tolerate intrathoracic operations with relative impunity is, no doubt, greater than the older and more limited experience had led us to believe. It is also probable that the impressions gathered from the fatality of unilateral pneumothorax in laboratory animals, especially dogs, had considerably magnified its frequency and importance in human surgery. But these conditions and concessions upon which we all agree do not detract from the indisputable fact that accidents and fatalities do occur when the pleura is opened in man whether on one side or both. Whatever the interpretation of these may be whether central, reflex, inhibitory, or due to the instability (flutter) of the mediastinal septum or air embolism, it matters not. The fact remains that a certain undetermined, and, thus far, undefinable percentage of the patients who are subjected to transpleural operations are susceptible and liable to untoward and dangerous manifestations which put their lives in jeopardy. As our distinguished fellow, Dr Robinson, once said in contrasting the different susceptibilities of the dog and rabbit to pneumothorax, "We never can tell when we are going to open a thorax of the dog or of the rabbit type in human surgery."

The present surgical situation in the thorax may be compared to that of the operator who faces a tumor or an aneurysm which may require the ligation of the common carotid artery. We know that the large majority of patients survive without serious cerebral accident or none at all, yet we also know that in a certain percentage, say 10 per cent, and more, in mature life, the operation will prove fatal or permanently disable the brain, hence our solicitude and anxiety to test whenever possible, the tolerance of the brain to a diminished circulation, by a provisional or tentative occlusion of the common carotid artery. And, in a similar way, when facing an open transpleural thoracotomy never knowing with certainty how the patient will behave when the pleura is opened, why should we not anticipate a possible emergency and protect the patient by the simple means of respiratory aid that are now at our command?

#### CONCLUSIONS

- 1 In view of the contradictory facts of clinical experience and the impossibility of predicting in any case what the pleuropulmonary reactions will be when the normal, nonadherent pleura is opened and the collapse of the lung takes place, it is only right that in any contemplated

intrathoracic operation in which a unilateral or bilateral pneumothorax may occur, precautions should be taken to forestall the accidents that may attend this condition

2 The difference between this attitude and that taken by the opponents of differential pressure or aided respiration is that they believe that there is only risk in bilateral pneumothorax and none whatever in the unilateral. It is on this point that we differ and take issue with them, because it is undeniable that in a certain, but undetermined, percentage of cases, the opening of one pleura may be attended by alarming or even fatal manifestations

3 To protect the patient against these unknown but possible dangers, the simplified methods of plus pressure ventilation of the lungs on the Meltzer-Auer principle are the safest and best for general use. Whether by the usual anesthetic face mask, by intratracheal intubation, or, preferably, by nasopharyngeal catheterization (the simplest and safest method), the requirements of anesthesia and pulmonary ventilation are combined in the gas-ether-oxygen sequence appliances, now in current use in almost every surgical clinic of this country. These deliver a steady stream of the combined or simple gases under a regulated plus-pressure sufficient to maintain the respiratory function of the lung during anesthesia

4 The objections on the score of expense, complexity, and cumbersome-ness that have been urged against respiratory aids in thoracic surgery are no longer tenable, nor does the special objection to "the inflated lung" as an obstacle to the intrathoracic technic hold good in view of the perfect control, at the present time, of the movements of the lung and of the maintenance of the respiration in spite of the collapsed state

# THE NEGATIVE CHAMBER IN OPEN PNEUMOTHORAX

A PERSONAL EXPERIENCE <sup>†</sup>

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NEW YORK

Open pneumothorax is the complete, sudden collapse of the lung which inevitably occurs when an operation requires the wide opening of the chest wall, in the absence of adhesions between visceral and costal or diaphragmatic pleura, or when an attempt is made to drain the chest after the method employed in other parts of the body.

The importance of preventing this physical phenomenon was fully realized by Dr. Matas more than twenty years ago, when, as one of the pioneers in the field of thoracic surgery in America, he had his assistant, Dr. Parham of New Orleans, excise a tumor of the chest wall with the help of a differential pressure apparatus, the Fell-O'Dwyer combination, as modified by Matas.

Ever since that time, open pneumothorax has been a topic for discussion. Our association considered it, at the second annual meeting, in 1919, when the president's address, which dwelt on the subject, was followed by a brief discussion. An afternoon devoted to the subject should perhaps enable us to arrive at a definite understanding of the first fundamental principle of thoracic surgery which it contains.

The topic will be reviewed from all the possible angles, it seems to me, if we discuss it from the following points of view: (1) the physical aspects of open pneumothorax, (2) the dangers for the patient from open pneumothorax, (3) the means at hand for avoiding these dangers, (4) the advisability or inadvisability of performing thoracic operations without such means.

I consider the first, second and fourth points settled <sup>1</sup>.

As regards the first point, the physical aspects of open pneumothorax, I accept as correct the statement that the dangerous features of the open pneumothorax—acute collapse of the lung—are due princi-

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<sup>†</sup>Read before the fourth annual meeting of the American Association for Thoracic Surgery, Boston, June 6, 1921.

<sup>1</sup> Cf. Meyer, Willy: The Necessity for the Application of Differential Air-Pressure in Thoracic Operations, *Med. Rec.* **96** 677 (Oct. 11) 1919, The Principles Underlying the Safe and More Rapid Evolution of Thoracic Surgery, *Am. J. M. Sc.* **109** 504 (Oct.) 1920, Fundamental Principles of Thoracic Surgery, *Med. Rec.* **99** 593 (April 9) 1921.

pally to the unbalancing of the mediastinum, which is restored and rendered harmless by the application of differential air pressure

As regards the second point, the dangers for the patient from open pneumothorax, I believe them to be real dangers, whether occurring during or subsequent to the operation. Therefore, the surgeon should, for the best interests of the patient, be prepared in every instance to avert these dangers

As regards the fourth point, the performance of thoracic operations without such preparation, I believe that occasional success in an intrathoracic operation performed with no special apparatus, and the work done without apparatus by many of our colleagues during the world war, should carry neither them nor us away in our deductions. It must be emphasized again that the experience gathered during the war was more or less confined to the traumatic chapter of thoracic surgery, to what in times of peace would be called emergency work. The patients of our colleagues who worked at and behind the front during the war almost without exception represented the flower of the manhood of America and other nations, young men, robust, hardened by drill, trained to endure hardship. Even these selected men had already been culled over, the most severely wounded and the weaker of those receiving chest wounds having died on the battle field. About 50 per cent of the chest cases thus dropped out, and the remaining 50 per cent must have been tolerant of the open (or temporarily closed) hemo-pneumothorax already established, when they reached the hands of the surgeon

In times of peace it is, apart from accident, mostly the weaker, the enfeebled human beings whom we are called on to save, with plenty of time, ordinarily, for careful individualizing, and with the patient's safety as the primary law

War surgery and peace surgery of the thorax appear to stand apart in their attending circumstances, and I can see no justification for transferring experience from one to the other without the most painstaking scrutiny. In peace, every case of intrathoracic advance calls for careful preparation. Only thus can danger incurred on entering a "virgin pleura," a pleural cavity without any adhesions as well as the dangers of postoperative acute pneumothorax in case of open drainage be met with prospects of success

In considering the means at hand for avoiding the dangers connected with open pneumothorax, I select from the four well-known useful methods now at our disposal for rendering intrathoracic surgery just as safe as surgical work in any other part of the body, the negative pressure chamber. It was the negative chamber which ushered in the skyrocket-like advance of the latest and last chapter of operative sur-



gery, and, but for the intense and frequent careful observation of the work done within the negative chamber, while it was temporarily in use at the Rockefeller Institute, by our first president, Dr Meltzer, he might never, or perhaps not so soon, have applied his ever-fertile mind to the solving of the problems of thoracic surgery

I feel it incumbent on myself to speak here of the negative chamber, because, to my regret, the Lenox Hill (formerly the German) Hospital of New York City has remained the only hospital in America that possesses such a chamber, and, therefore, practically only I and those who have worked with me in it, can report experiences in its use, which I shall submit to you briefly

The negative chamber of the Lenox Hill Hospital is a perfect piece of mechanism outside of a few dollars for the renewal of a rubber collar, it has not cost one cent for maintenance or repairs during the ten years of its existence. It is in every way as perfect today as it was in 1911. Owing to its transformation from a portable experimental apparatus into a stationary structure for hospital use, it was not feasible to arrange drainage for washing it down with a hose stream. Asepsis in the chamber has, nevertheless, always been perfect, only it is slightly more troublesome to maintain, but this is a feature which, if we had to do the work over again and were constructing for permanency from the start, could be readily eliminated<sup>2</sup>

On occasion, a negative chamber was discussed of round instead of the present rectangular shape, constructed on the lines of a large oil tank, the hood of the positive cabinet also tank-shaped, which accommodates the head of the patient, projecting into the former, access to it being from the outside. Verbal communication between those in either could be held, as now, through diaphragms in the frame of the cabinet. Such a chamber could be thoroughly washed down after every operation and the remaining moisture evaporated by starting the blowers. The price could probably be brought down considerably below that of the Lenox Hill Hospital chamber, which, being a first attempt and of special construction, cannot be considered a criterion for cost.

Strange to say, the Lenox Hill Hospital chamber, neither in its experimental nor in its final shape, has been used in the physiologic tests for which it was planned, viz, to ascertain which of the two pressures is best for sick and weak persons, the negative or the positive. When it was ready for use, there was immediately such a flood of surgical questions pressing for investigation that there was no opportunity for taking up physiologic problems. Besides, in the period from 1908 to 1911, while our negative pressure chamber was passing through

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2 Keen Surgery, Philadelphia, W B Saunders, Vol 3, pp 526-527

a course of development a rapidly increasing number of positive pressure methods came to the front, and as these devices were tested and found satisfactory the world over the urgency of physiologic questions had passed—at least for the time being. Moreover, these devices have certain advantages over the bulky immovable chamber—they can be brought into the general operating room, or to the bedside of the patient—it is not necessary to shift the whole operating organization of surgeon staff men and nurses nor the patient to the special operating room in which the chamber is located. These considerations became especially important when the effects of the war began to be felt in our hospital as in other—through loss of nurses lack of applicants and disruption generally of the regular hospital work. For that reason I have since 1916 used positive pressure apparatus in my thoracic work and have performed the operations in the general operating room. Now with peace returned and with working conditions at our hospital gradually improving it is hoped that work within the negative chamber will be resumed.

Here I want to make a brief report of personal work done in the negative chamber. We have operated there from May, 1911 to December 1915 twenty times on patients who were suffering from various types of thoracic disease. Fifteen made an operative recovery and five died, three from twenty-four to forty-eight hours after the operation and two on the operating table, one of the latter after completion of the operation.

Seven exploratory thoracotomies were performed with seven operative recoveries, five for cancer of the esophagus, one for an organic cicatricial stricture of the cardia, one for a diffuse aortic aneurysm which extended from the arch of the aorta almost to the foramen of the diaphragm.

Additional exploratory thoracotomy was performed for sarcoma of the upper lobe of the lung in one case, which proved inoperable as the tumor had transgressed the lung proper and invaded the surrounding muscular area. The temperature rose, and the patient died on the day following the operation. Necropsy was not performed.

Resection of the manubrium sterni with adjacent rib cartilages, intended as a decompression, was performed, in a case of far advanced malignant tumor of the anterior mediastinum. When the operation had been completed and the dressing was being applied, the patient died suddenly. On looking up the literature I found that Sauerbruch lays stress on the use of positive pressure in all cases of tracheal compression.

Thoracotomy was performed in a case of bilateral bronchiectasis of long duration with complete pneumolysis on one side. Closure was followed by recovery. This case has been referred to in the text.

Ligations of a branch of the pulmonary artery for advanced bronchiectasis was performed in three cases, with operative recovery. Attempt at excision of the right upper lobe of the lung for an abscess of long standing was made in one case, with fatal issue, owing to a profuse arterial hemorrhage from a mass of small arteries, on loosening the firmly adherent lung. A wrong point

of cleavage had been entered and the endothoracic fascia stripped from a portion of the chest, this fascia forming an absolute unit with the costal pleura. Necropsy revealed that incision of the abscess with drainage would have been the better plan. This experience led to the resolve never to enter the thorax with a fixed program—here, lobectomy—but to be guided in the indication for operation by the direct findings in the given case.

In one case, vagolysis with esophagoplication of the supradiaphragmatic pouch, for cardiospasm, was performed, with recovery.

Cardioplasty was performed later on, on the last mentioned patient, by means of longitudinal incision down to the mucosa, transverse suture and free fascia transplantation, with recovery.

Resections of the esophagus for cancer, by the transthoracic route, were made in four cases. One patient died on the table, after completion of the operation, two died in the course of the first and second twenty-four hours, respectively, one patient, in whom a two-stage operation had been contemplated after gastrostomy, recovered nicely after division of the esophagus below the tumor and inversion of either end, the chest being freely drained, with the patient remaining under differential pressure for twenty hours. He was out of bed after a few days. Then the inversion of the proximal stump gave way, and an esophageal fistula developed. He died a few weeks later as a result of a perforation of the tumor into the bronchus, which caused septic pneumonia.

All these operations were transthoracic, with the exception of one, and were done prior to the advent of esophageal resection with antethoracic transposition of the proximal esophageal stump, and prior to the introduction of airtight postoperative thoracic drainage.

This report refers only to operations carried out within the negative chamber. But in only a certain percentage of patients suffering from thoracic lesions operated on in the thoracic pavilion was the operation performed in the chamber. The thoracic pavilion is fitted up for the use of all the differential pressure methods, and they were used from the start for the purpose of determining the type of apparatus best adapted to the case in hand.

Many of the cases cited have been published before in greater detail, from my records, and from the official records of our hospital, but they have never before been published collectively.

I feel that I owe this report of my work in the negative chamber not only to myself but also to the chamber, and above all to the man who, as an assistant, worked it out in theory as well as in practice, Ferdinand Sauerbruch. The reputation of the chamber should not be permitted to suffer because of its use at a time when we did not know the best technic in the many problems of thoracic surgery, and when surgery of the esophagus was in the very beginning of its development. Nor should it suffer any longer from the myth that all patients operated on in the chamber have died immediately.

We have had deaths, first, because, during the initial years of our thoracic work we were mere tyros, often groping in the dark in trying

to solve the technical problem before us, and then particularly because the indications were often poorly interpreted. Patients with far advanced intrathoracic disease were operated on radically in cases that we would not think of subjecting to radical work today.

I further wished to make these brief statements in order to have at last appear in print, if only in part, the more exhaustive report I made before the clinical society of our hospital April 13, 1917, entitled 'The Pavilion for Thoracic Surgery of the German Hospital.' It gave a synopsis of all the cases in which operation had been performed at the pavilion up to that time, but could not be made ready for publication because of lack of time.

There are colleagues who, for various reasons, abhor work under the unaccustomed and unusual conditions represented in the negative chamber. That cannot be helped. For me, thoracic work within the chamber always had a peculiar fascination. I am anticipating the first operation that will be performed in the chamber now that we have learned—at least in the majority of intrathoracic diseases—how to proceed in the given case.

For a while, it seemed that the present status of esophageal surgery necessitating operation also on the neck (external esophagotomy) would permanently exclude the use of the chamber in this class of case, on account of the rubber collar around the patient's neck. However, a slight change in the construction of the hood of the positive cabinet which harbors the patient's head, and a combination with the modification of the negative chamber proposed by K. H. Gieritz of Umeå, Sweden, as also the attack on the esophagus by means of posterior mediastinotomy, may gradually adapt the negative chamber again to surgical work of this type.

It certainly is my firm belief that the negative chamber, together with the various useful positive pressure apparatus at our command, has its definite place in every well conducted hospital desirous of doing intrathoracic work *in all its phases*, and always placing the best interests of the patient in the first line. Some lives, otherwise lost, might be saved with its help.

Are the positive pressure apparatus in practice really just as good, just as safe *for the patient*, particularly for the weak and reduced chronic invalid suffering from thoracic disease? In 1904, the German Physiologic Society decided in favor of negative pressure, declaring it to be the most physiologic differential pressure method for thoracic operations. Davies<sup>3</sup> says, in a chapter on apparatus for the control of

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<sup>3</sup> Davies, H. M. The Surgery of the Lung and Pleura, New York: Paul B. Hoeber, 1920.

emergencies in the easiest way. The patient's mouth is free and unobstructed, anesthesia is absolutely the same as in any other operation, operating under local and regional anesthesia is feasible.

On the other hand, when the mask is used (Tiegel, Robinson, Gwathmey), a vomiting spell of the patient is an unwelcome occurrence, intratracheal insufflation requires the introduction of the catheter with the patient in deep general anesthesia, intrapharyngeal insufflation also requires general anesthesia for the introduction and temporary presence of the nasal tubes, although it appears plausible that repeated thorough cocainization might abolish the reflexes of the nasal and pharyngeal cavity, thus rendering general anesthesia unnecessary.

In having the negative chamber, which represents a large pleural cavity in the true sense of the word, we are prepared to meet every contingency. This would be particularly appreciated by surgeons working in hospitals having a large ambulance service.

In these times of frequent motor accidents it is not difficult to imagine a case of severe chest injury in which the patient might be saved, if it were at all possible, by the use of the negative chamber.

A patient who has been run over by an automobile is unconscious, several ribs are broken, there is no external wound, the pleura is evidently torn from within, there is pronounced anemia due to acute loss of blood, and at frequent intervals foam blood is brought up through the mouth, evidently from the pleural cavity, which is filled with blood and air. At the neck, there is distinct emphysema. In addition, there are repeated vomiting spells due to a concussion of the brain, with or without a skull fracture. The patient is carried into the chamber, placed on the operating table, and the head pushed through the rubber collar, the assistants, nurses and instrumentarium are ready, the doors are closed, and the pressure is turned on, and any emergency can be met in the most physiologic and gentle way. Rapid creation of the desired differential pressure in all its details can be carried out by a nurse or any hospital attendant, a specially trained medical man is not required. The first trained man on hand opens the chest, stops the hemorrhage, sutures the torn lung, etc. The oxygen tank, several of which are always on hand in the anesthetist's cabinet, which holds also the patient's head, is connected with a proper mask put loosely over the patient's mouth, allowing additional inhalation of oxygen under pressure. If, in spite of everything, spontaneous respiration suddenly ceases, the mere raising and lowering of a lever within the chamber will instantaneously effect artificial respiration, which will be thorough and effective as long as the glottis is not closed by spasm. Rhythmic distention and collapse of the exposed lung will tell whether the access of the air is unobstructed. But—to continue the imaginary case—it

open pneumothorax, "The great advantage of this method [the use of the hypo-atmospheric chamber, as he terms it] is that not only the lung but also the large veins of the chest are exposed to a negative pressure and are therefore under very nearly normal physiological conditions." I shall always remember the words of a medical friend, from whose experience and advice I often profited, when, in the negative chamber and in his presence, I performed a thoracotomy on a weak, anemic and enfeebled girl with a bilateral bronchiectasis, that in all his thoracic work he had never before seen a seriously ill patient stand so easily and so plainly without deleterious consequences operative work within the chest.

As regards the effect of positive pressure on the circulation, there can be no question that the capillary vessels which run within the walls of the innumerable alveoli of the lung, taking care of the proper exchange of gases, are somewhat compressed by the increased air pressure, produced by positive pressure apparatus of any type, viz, plus-pressure cabinet, mask, intratracheal and intrapleural insufflation, and that, consequently, the right side of the heart is called on to do extra work, and hence is liable to acute dilatation during or after the surgeon's work.

Of course, absolute scientific proof for this assumption can probably not be given, but logical thinking and unbiased reasoning will tell us that it must be so. For that reason, in order to give the heart muscle a brief time for regaining its tone, surgeons let the pressure produced by the apparatus often drop to zero, at intervals, in the course of a prolonged thoracic operation, when using positive pressure apparatus. All this may not mean much, if anything, in a strong patient, however, in the chronic invalid, who has suffered for years with a greatly weakened, often chronically inflamed heart muscle (chronic myocarditis), it may mean much.

Another point which deserves mention in this connection with regard to weakened patients is the loss of body heat, a fact which does not have to be reckoned with in the chamber, where, because of the electric illumination, a uniformly elevated temperature can be obtained, in spite of the continuous ventilation. That this loss of body heat represents an important factor in thoracic work, in which so large an interior surface of the body is exposed to the broad access of the atmospheric air, has been pointed out by many authors.

Looking over the positive pressure apparatus at hand with reference to anesthesia, we find that the pressure cabinet, as developed within the negative chamber, taking care of the patient's head and affording the anesthetist access to trachea and esophagus, enables us to meet all

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A patient who has been run over by an automobile is unconscious, several ribs are broken, there is no external wound, the pleura is evidently torn from within, there is pronounced anemia due to acute loss of blood, and at frequent intervals foamy blood is brought up through the mouth, evidently from the pleural cavity, which is filled with blood and air. At the neck, there is distinct emphysema. In addition, there are repeated vomiting spells due to a concussion of the brain with or without a skull fracture. The patient is carried into the chamber, placed on the operating table, and the head pushed through the rubber collar, the assistants, nurses and instrumentarium are ready, the doors are closed, and the pressure is turned on, and any emergency can be met in the most physiologic and gentle way. Rapid creation of the desired differential pressure in all its details can be carried out by a nurse or any hospital attendant, a specially trained medical man is not required. The first trained man on hand opens the chest, stops the hemorrhage, sutures the torn lung, etc. The oxygen tank, several of which are always on hand in the anesthetist's cabinet, which holds also the patient's head, is connected with a proper mask put loosely over the patient's mouth, allowing additional inhalation of oxygen under pressure. If, in spite of everything, spontaneous respiration suddenly ceases, the mere raising and lowering of a lever within the chamber will instantaneously effect artificial respiration, which will be thorough and effective as long as the glottis is not closed by spasm. Rhythmical distention and collapse of the exposed lung will tell whether the access of the air is unobstructed. But—to continue the imaginary case—it



appears that the lung does not respond to the pressure changes produced by the level movements. Routine compulsory training has prepared the members of the house staff also for this emergency. An O'Dwyer tube is quickly introduced, and when it is properly in place the artificial ventilation of the lungs continues, oxygen being again added, and if luck favors the patient, spontaneous respiration is resumed and the way opened for ultimate recovery.

One more example. A patient is brought in with a wound of the heart. To my mind these cases in our large hospitals should as a rule be operated on under differential pressure, and if it is at all feasible, under regional and local anesthesia. Many heart wounds are complicated with pleural injury, hemopneumothorax being present. In the course of the exploration of the heart, the pleural wound may have to be enlarged or it will tear further at the site of the rent. The surgeon's worries from the ensuing complete collapse of the lung, which may determine the patient's fate if not counterbalanced, surely ought to be eliminated. He ought to have ample time also to evacuate and clean the pleural cavity. Employment of differential pressure will do this, and the mere placing of the patient under negative pressure will answer the purpose. The surgeon then can leisurely attend to evacuating and cleansing the pleural cavity, and take such steps as he may deem necessary and best for the patient's welfare.

One of the members of our association once wrote me these significant words: "The most suitable apparatus is one that can be used by any surgeon in any case." The negative chamber certainly belongs most preeminently to that type of apparatus.

The more I have thought about the negative chamber—and certainly not because only our hospital is in the possession of the apparatus—the more I am convinced that it would be a real pity if our great medical institutions of learning should consider the chamber an antiquated piece of apparatus, and would not entertain the idea of its use, because it is more cumbersome and more expensive than other apparatus. The question of somewhat greater expense and, albeit, slight inconvenience, should not stand in the way of our doing the very best for our patients.

But I should not like to be misunderstood. I do not mean to imply that the negative chamber should take first place among the four methods of differential air pressure, or that it should supersede the others. What I mean to say is that it should have its place among the various methods, and that we, in order to be properly prepared for all emergencies that may present themselves, cannot well afford to do without the negative chamber. If the hospitals want to give their

patients suffering from thoracic disease the benefit of the very best that science offers, they must place at the disposal of the specialist in thoracic surgery all four of the well-known useful apparatus, so he may be in a position to select the method he deems best, the method that experience has taught him or others is best adapted for the case in hand

Let us adapt the apparatus to the patient, and not the patient to the apparatus

# THE VALUE OF VENTRICULOGRAMS IN THE LOCALIZATION OF INTRACRANIAL LESIONS

## THREE CASES OF OBSTRUCTIVE HYDROCEPHALUS AND ONE OF BRAIN TUMOR

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SAN FRANCISCO

In 1918 Dandy<sup>1</sup> proposed the employment of roentgenograms of air-filled cerebral ventricles for the differentiation of the types of hydrocephalus and for the localization of brain tumors. He said, "For the first time we have a means of diagnosing internal hydrocephalus in the early stages. Without the ventriculogram, the diagnosis is frequently guesswork, with the ventriculogram, the diagnosis is absolute." Dandy's later reports have confirmed his estimate of the value of the ventriculogram in hydrocephalus, and he<sup>2</sup> has reported two cerebral tumors in which "there was no sign by which the location of the tumors was even suspected. In both, the ventriculograms showed the precise location of the growth." Frazier's<sup>3</sup> statement, "Thus far it has not aided me in establishing the location of a growth not indicated by other signs," would indicate that the value of the procedure is not yet generally appreciated.

I have used the method in four cases. Three were different types of obstructive internal hydrocephalus in infants, and in each, the site of the obstruction was demonstrated by the ventriculogram. One of these cases is an example of the rare condition of obstructive hydrocephalus of one lateral ventricle. In the fourth case, the clinical symptoms suggested a frontal lobe tumor, but there was nothing to indicate which hemisphere was involved. The ventriculogram showed that it lay on the left side where it was found at operation.

### REPORT OF CASES

CASE 1 (Disp No 95803) — *Advanced hydrocephalus due to occlusion of the foramina of Magendie and Luschka, formation of a new foramen of Magendie, death five weeks later, no necropsy*

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1 Dandy, W E. Ventriculography Following the Injection of Air into the Cerebral Ventricles, *Ann Surg* **68** 5 (July) 1918

2 Dandy, W E. Localization or Elimination of Cerebral Tumors by Ventriculography, *Surg, Gynec & Obst* **30** 329 (April) 1920

3 Frazier, C H. The Achievements and Limitations of Neurologic Surgery. *Arch Surg* **3** 543 (Nov) 1921

*History*—B, a girl, aged 6 weeks, was admitted to Lane Hospital, May 16, 1921. She was a first child, born normally at full term. She was next seen by the physician in the fifth week, when she showed a marked enlargement of the head. Dr. G. F. Helsley of Fresno saw her in consultation and sent her to San Francisco.

*Examination*—The child weighed 4200 gm. The occipitofrontal circumference of the head was 46.5 cm. Near the anterior end of the posterior fontanel could be felt what appeared to be the junction of the lateral and superior longitudinal sinuses. The optic disks were white. The arms and legs were spastic and frequently exhibited short tonic spasms. Spinal puncture was performed twice, both times air sucked through the needle when the child cried, but no fluid was obtained. Nine hundred cc. of cerebrospinal fluid were aspirated through the anterior fontanel and replaced by the same amount of air. The roentgenograms showed great dilatation of the lateral, third and fourth ventricles, with marked thinning of the cortex. The lateral sinus crossed the posterior fontanel 4 cm. anterior to the upper edge of the occipital bone, and all below this was fourth ventricle (Fig. 1). The foramina of Magendie and Luschka were occluded so that fluid could not pass from the fourth ventricle into the subarachnoid spaces.

*Operation* (Towne)—May 21, through a midline incision the muscles were separated down to the occipital bone, an area of bone was removed, and the dura was opened. Under the dura and not adherent to it was the paper-thin wall of the cystic fourth ventricle. This was opened, allowing the head to collapse as the air escaped. The dura, muscle and skin were sutured.

*Postoperative Course*—The wound healed cleanly. The circumference of the head was 45 cm., May 27, 44.5 cm. May 31, 44 cm., June 6, and 43.5 cm., June 8, when the child was discharged from the hospital. By letters from the parents it was learned that the head began to enlarge again about ten days after discharge. June 23, the circumference was 50 cm. Death occurred, June 28, following a series of convulsions. There was no necropsy.

Dandy<sup>4</sup> has pointed out the treatment for this type of hydrocephalus. He made new foramina of Magendie for two adults in whom the occlusion was due to meningitis, and both were cured. In his one congenital case, the patient, an infant aged 3 months, died when the cystic fourth ventricle was opened. The operation is physiologically correct, easily performed, and, to judge from my case, well borne by the infant. The diagnosis was made too late. When the head begins to enlarge the cortex is already markedly thinned. Earlier than this stage the diagnosis may be suspected but can be confirmed only by the ventriculogram. Operation before enlargement of the head offers a prospect of recovery without serious damage to the optic nerves and cortex. Lacking postmortem examination, it is impossible to say whether the new foramen failed to function, or whether, because of a pathologic condition in the subarachnoid spaces, an obstructive hydrocephalus was converted into a communicating hydrocephalus.

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4 Dandy, W. E. The Diagnosis and Treatment of Hydrocephalus Due to Occlusions of the Foramina of Magendie and Luschka. *Surg. Gynec. & Obst.* 32: 112 (Feb.) 1921.

In the next case, I was associated with Dr P K Gilman, to whom I am indebted for permission to use the case in this report

CASE 2 (Hosp No 25003) —*Advanced hydrocephalus due to occlusion of the aqueduct of Sylvius not cured by the formation of a new aqueduct, extirpation of a choroid plexus, death, no necropsy*

*History*—M M, a girl, aged 8 weeks, was admitted to Lane Hospital, July 5, 1921. She was the first child of a 33 year old mother, and was delivered by cesarean section because of hydrocephalus. From the sixth to the twentieth day the circumference of the head remained stationary at 41 cm. Beginning the sixth week the head enlarged rapidly.

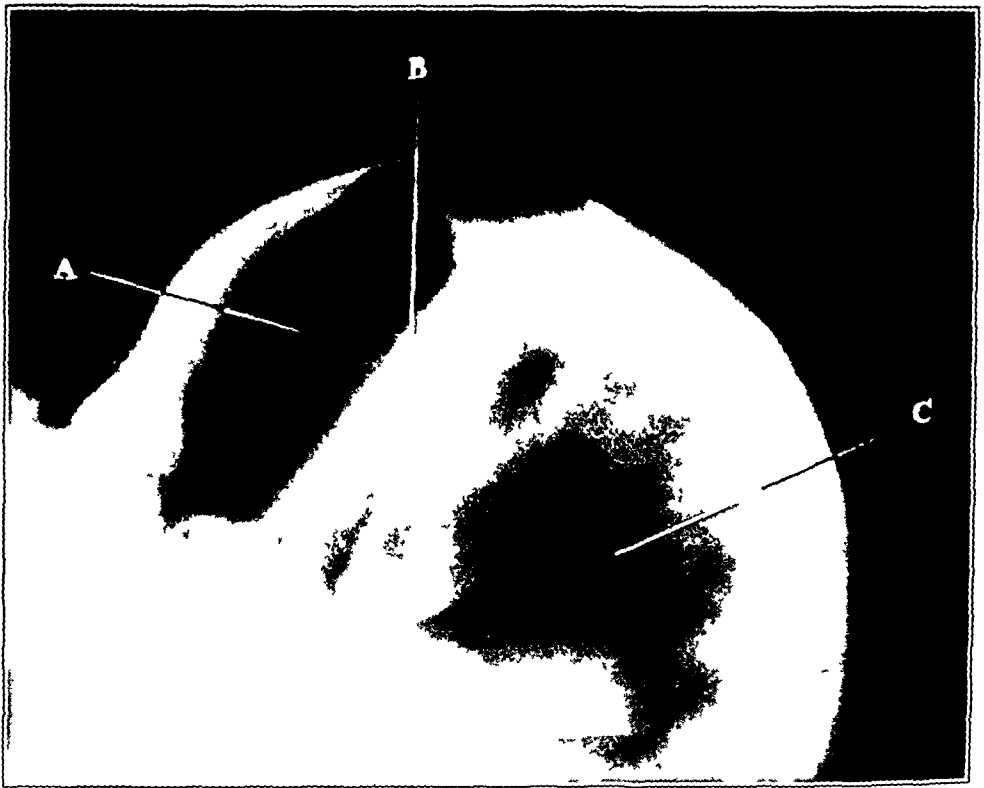


Fig 1 (Case 1) —Occlusion of foramina of Magendie and Luschka. *a*, fourth ventricle, *b*, tentorium cerebelli, *c*, third and lateral ventricles, lateral projection with horizontal ray, face down.

*Examination*—The child weighed 5,400 gm. The occipitofrontal circumference of the head was 53 cm. The optic disks were white. There was an abnormality of the left great toe, shown by the roentgen ray to be due to absence of both phalanges. A half hour after injection of 1 cc of indigo-carmin into a lateral ventricle, spinal puncture gave colorless fluid which dropped slowly and stopped when 5 cc had been collected. Fifteen hundred cc of fluid were aspirated from the ventricle and replaced by the same amount of air. The roentgen ray disclosed an extreme degree of brain destruction with air in the lateral and third ventricles but with none in the fourth ventricle (Fig 2). The aqueduct of Sylvius was occluded so that fluid could not pass from the third to the fourth ventricle.

*First Operation* (Gilman)—July 12, the occipital muscles were separated in midline, an area of bone including the posterior half of the foramen magnum was removed, and the dura was opened. The vermis was divided in midline to expose the floor of the fourth ventricle. A probe was thrust through into the third ventricle, and a fenestrated rubber catheter was placed in the new aqueduct. The posterior end of the catheter was sutured to the dura, and the wound was closed.

*Postoperative Course*—There was a very severe reaction and the child's condition was precarious for several days. By percussion of the head the reaccumulation of fluid could be followed. Roentgenograms taken, July 18 showed that the head was about half full, and indicated that the tube was



Fig 2 (Case 2)—Occlusion of aqueduct of Sylvius, lateral projection with vertical ray

functioning, if at all, only through the eye at the end (Fig 3). August 1 the tube was removed. Measurements from August 4 to 7 showed that the circumference of the head was increasing at the rate of 1 cm a day. August 13, spinal puncture gave 15 cc of fluid.

*Second Operation* (Gilman)—August 15, the choroid plexus of the left lateral ventricle was removed. The child died three hours later. Necropsy was not obtained.

In this case there was little possibility of a favorable outcome, for, even if treatment had been undertaken immediately after birth the cortex was then badly damaged. With the diagnosis made the parents

insisted that an attempt be made to relieve the condition. The point of obstruction was attacked, but either the new aqueduct did not function or the fluid could not be cared for in the subarachnoid spaces. Dandy<sup>5</sup> has shown that this operation is successful in a less advanced case, one of his patients was alive and apparently normal a year afterward. The second intervention was undertaken on the theory that fluid having flown quite freely by spinal puncture, the new aqueduct

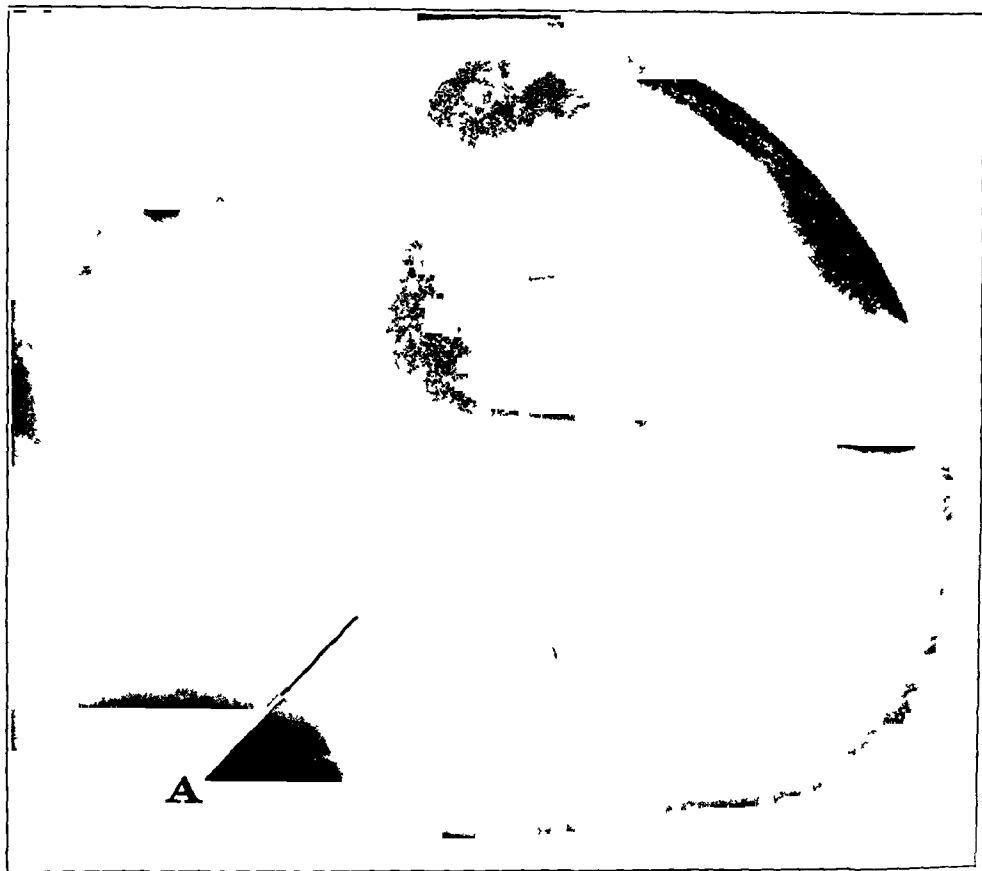


Fig 3 (Case 2)—A, catheter (retouched) in the reestablished aqueduct of Sylvius, lateral projection with horizontal ray, occiput down

was probably functioning and we were dealing with a communicating hydrocephalus. Unfortunately, this question was not settled by dye injection, further ventriculograms or necropsy.

CASE 3 (Disp No 96080)—*Obstructive hydrocephalus of the right lateral ventricle, extirpation of choroid plexus, death necropsy, glioma of the left cerebral hemisphere*

5 Dandy, W E. The Diagnosis and Treatment of Hydrocephalus Resulting from Strictures of the Aqueduct of Sylvius. *Surg, Gynec & Obst* 31:340 (Oct) 1920

*History*—W C, a boy, aged 6 weeks, was admitted to the pediatrics service of Dr H K Faber in Lane Hospital, Aug 8, 1921. He was the third child, born normally at full term. On the tenth day the mother thought that the fontanels were wider than at birth. On the fourteenth day the left side of the face began to twitch, and this occurred frequently for about two weeks. There was rapid enlargement of the head during the ten days before admission.

*Examination*—The child weighed 5,290 gm. The occipitofrontal circumference of the head was 46.5 cm. The optic disks were white. The arms and legs were slightly spastic and the left tendon reflexes were sharper than the right. A hypodermic needle was introduced through the left angle of the anterior fontanel, a small amount of cerebrospinal fluid was aspirated and 1 cc of indigocarmin was injected at that point. Twenty-five minutes later, spinal puncture gave a few cubic centimeters of uncolored fluid that dropped

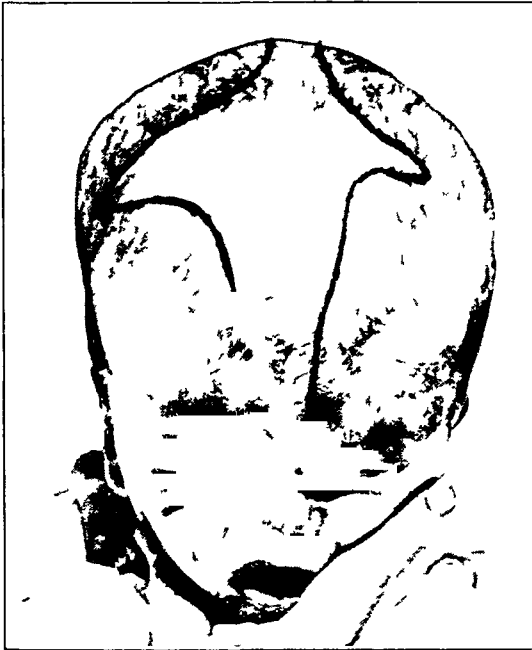


Fig 4 (Case 3)—Asymmetrical enlargement of the anterior fontanel

slowly. A spinal puncture needle was passed through the left angle of the fontanel to a depth of 4 cm, but no fluid was obtained. It was then observed that the fontanel was enlarged to the right more than to the left (Fig 4). The needle was introduced through the right angle of the fontanel, and 500 cc of colorless fluid were removed and replaced by the same amount of air. The lateral projections were vertical and horizontal rays revealed dilatation of one or both lateral ventricles. The anteroposterior projection with the horizontal ray demonstrated that the right lateral ventricle was tremendously enlarged and incompletely filled with air and that no air had passed into the left lateral ventricle (Figs 5 and 6). The preoperative diagnosis was hydrocephalus of the right lateral ventricle resulting from occlusion of the foramen of Monro.

*Operation* (Towne)—August 17 the choroid plexus of the right lateral ventricle was extirpated. Though practically no blood was lost the child went into collapse when the ventricle was opened and died two hours later.



*Necropsy*—The brain was placed in liquor formaldehydi, after fixation, the right lateral ventricle was filled with gelatin. The right cerebral hemisphere was three or four times larger than the left (Fig 7). Three transverse sections were made and the ventricles and interventricular passages were dissected. The gelatin mass was in the right lateral and third ventricles. The left lateral ventricle was collapsed and displaced posteriorly by a large infiltrating tumor of the left cerebral hemisphere. At Level 3 (frontal) the tumor was degenerated (Fig 8). At Level 2 (parietal) it comprised more than half the hemisphere, extended well across the midline and displaced the anterior horn of the left lateral ventricle upward (Fig 9). At Level 1 (occipital) the mass



Fig 5 (Case 3)—Occlusion of right foramen of Monro, *a*, fluid level, anteroposterior projection with horizontal ray, right side down

was bounded medially and superiorly by the great longitudinal fissure, laterally by the left lateral ventricle and inferiorly by the thalamus (Fig 10). Dissection posterior to Level 1 uncovered the left foramen of Monro opening into the posterior end of the elongated third ventricle. All of the tumor lay anterior to the left foramen, and it apparently arose from the left anterior crus of the fornix or from the white matter farther forward. The foramina of Monro entered the third ventricle 2.5 cm apart, the right at its anterior and the left at its posterior end. The right foramen was patent, but elongated and tortuous from the encroachment of the tumor across the midline. The aqueduct of Sylvius and the fourth ventricle were normal. No corpus callosum could be found. Microscopic examination of the tumor showed it to be a glioma.

In this case the unilateral hydrocephalus might have been suspected from the asymmetry of the fontanel had the head been more carefully observed before the dye and fluid-replacement studies were begun. The dye was probably placed in the great longitudinal fissure, for no trace of it was found in the left hemisphere, moreover, fluid having been aspirated at the point of injection, the indigocarmín must have been placed in the subarachnoid space. The degenerated area of the glioma corresponded closely to the region to which the spinal needle was passed on the left side, and may have been due to hemorrhage caused by the

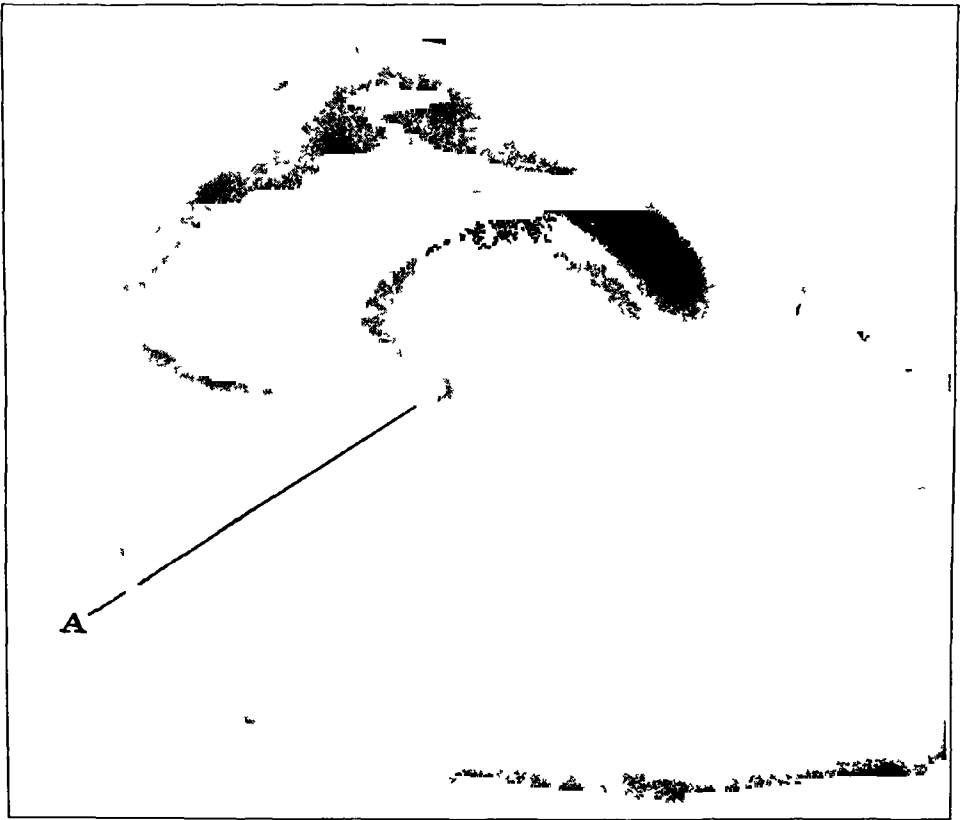


Fig 6 (Case 3)—A fluid level anteroposterior projection with horizontal ray, left side down

needle. The presence of a tumor not being suspected it was thought that we might be dealing with a congenital absence of the foramen of Monro, as in the case described by Bransford Lewis<sup>6</sup>. For this condition the establishment of a communication between the lateral and third ventricles would be the proper procedure, but at operation it was not possible to be sure where the third ventricle lay. I, therefore, removed the choroid plexus, with some misgiving as to the fate of the great

<sup>6</sup> Lewis Bransford. Unilateral Internal Hydrocephalus from Closure of the Foramen of Monro—Death—Autopsy. *Alienist & Neurologist* 8:396 1887

dead space should the child survive. Dandy<sup>7</sup> found that when the ventricles were small the operation was well tolerated, but that when they were enlarged and the cortex was greatly thinned the reaction was severe or fatal.

I am not able to explain satisfactorily all the postmortem findings. It is clear that the right foramen of Monro, although patent, did not function properly, and that this must have been due to the pressure of the tumor. The elongation of the third ventricle was caused by

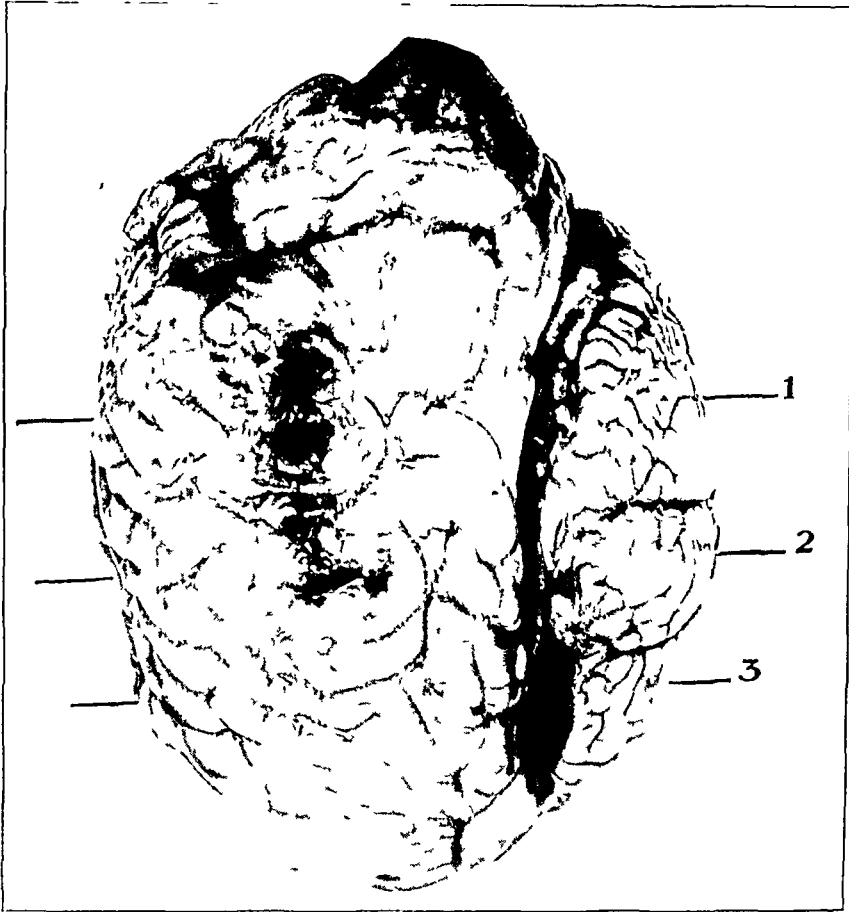


Fig 7 (Case 3)—Levels of transverse sections shown in Figures 8, 9 and 10 indicated by 3, 2 and 1, defect on superior aspect of right hemisphere is an enlargement of the operative incision.

the backward displacement of the left foramen of Monro. But the third ventricle was also dilated, and this is difficult to understand in view of the patency of the aqueduct of Sylvius and the collapsed condition of the left ventricle. It would seem that a tumor arising in the vicinity of the anterior crus of the fornix and pushing the foramen of

<sup>7</sup> Dandy, W. E. Extirpation of the Choroid Plexus of the Lateral Ventricles in Communicating Hydrocephalus, *Ann Surg* 68:569 (Dec) 1918.

Monro back into the occipital region would have blocked that foramen rather than the one on the opposite side. Perhaps the absence of the corpus callosum made it possible for this dislocation to occur without occlusion of the left foramen.

CASE 4 (Disp No 99658) — *A brain tumor localized in the left cerebral hemisphere by ventriculogram, cystic glioma of temporo-sphenoidal lobe found at operation, recovery*

*History* — L. C., a woman, aged 53 years, was admitted, Oct 20, 1921, to the neurologic service of Dr. Walter F. Schaller in Lane Hospital, recommended



Fig 8 (Case 3) — Transverse frontal section at Level 3 (Fig 7) a, degenerated area of tumor in left hemisphere

by Dr. R. V. Lee of San Francisco with the diagnosis of brain tumor. There was nothing important in the family or past history. Twelve years previously, in 1909, she began to have attacks of petit mal, rare at first but increasingly frequent after 1916. During the past year there had been about twelve major convulsions with loss of consciousness. Neither the major nor minor attacks were jacksonian in character. For a year there had been loss of memory and periods of disorientation. On questioning, a relative gave an indefinite history of recent slowness in understanding spoken and written words. She had complained for five months of mild headaches, nausea, dizziness, and transitory blurring of vision.

*Examination*—The skull was normal to palpation and percussion. Roentgenograms revealed generalized thickening of the cranial bones. There were choked disks measuring 6 diopters. The visual fields were normal. The vision was right, 15/30, left, 15/20. The remaining cranial nerves were negative. Muscle tone and power, sensibility and reflexes were normal. There was marked fine tremor of the hands, but no ataxia, dysmetria or Romberg's sign. Her memory was defective for past and recent events. She was oriented for time and place. No motor or sensory aphasia could be demonstrated by careful tests. The tentative diagnosis was tumor of the frontal lobe, side unknown.

October 26, with procain and epinephrin anesthesia, a small trephine opening was made at Kocher's point, and through it 25 c.c. of cerebrospinal fluid were



Fig 9 (Case 3)—Transverse parietal section at Level 2 (Fig 7) *a*, left lateral ventricle, tip of anterior horn, *b*, tumor

aspirated from the anterior horn of the right lateral ventricle and replaced by the same amount of air. No more fluid could be obtained though the patient was in the correct position—face down and turned slightly to the left. She was then placed with the occiput down, and the head was slowly turned to the right. Roentgenograms were taken after she had been in the right lateral position for half an hour. The turning was then reversed and more exposures were made in the left lateral position. The right and left lateral projections with vertical and horizontal rays revealed the outlines of an apparently normal ventricle. With the anteroposterior projections with the horizontal ray, air was seen only in the right lateral ventricle (Fig 11). Fearing that the turning of the head to allow the air to pass into the left ventricle had not been properly carried

out, it was repeated the next day according to Dandy's<sup>8</sup> directions 'In normal or slightly enlarged ventricles the air passes from one ventricle to the other when the position of the head is such (occiput down) that all the air is in the anterior horn. If the head is then turned toward the side containing the air, air passes through the interventricular foramina to the opposite lateral ventricle.' The result was the same, no demonstrable air had passed into the left lateral ventricle. The preoperative diagnosis was a tumor of the left frontal or temporosphenoidal lobe, compressing the left lateral ventricle.

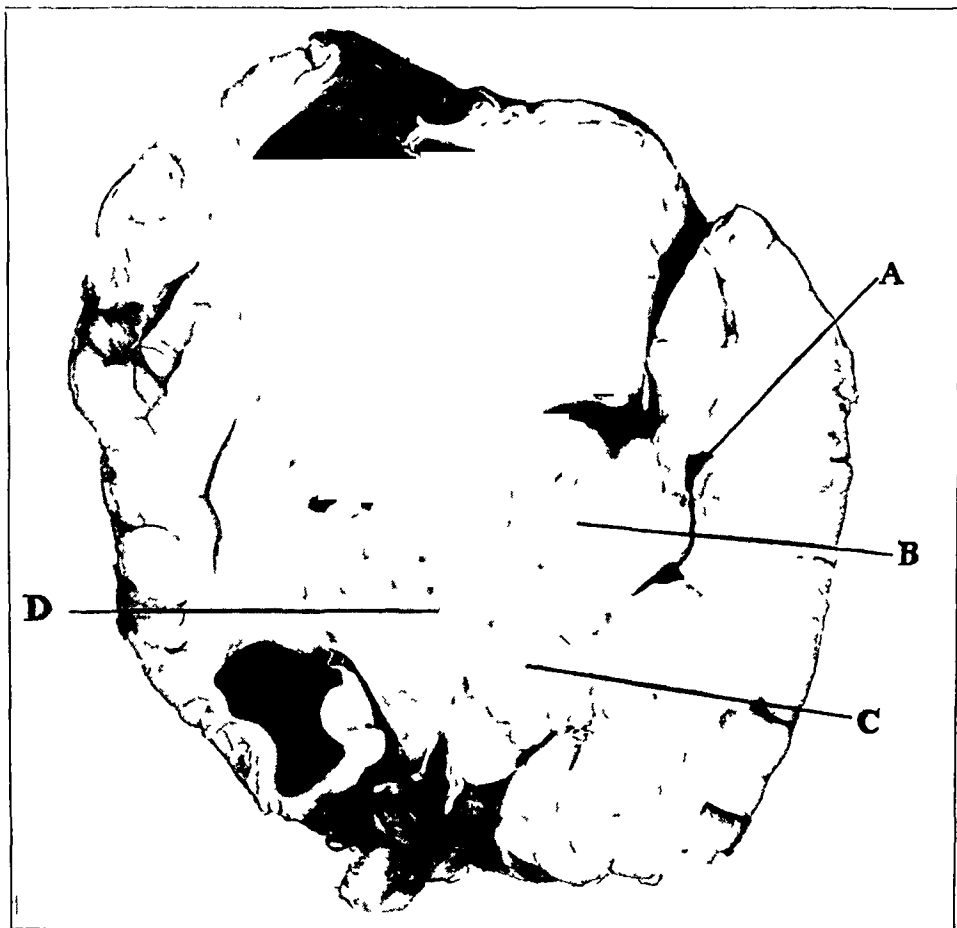


Fig 10 (Case 3)—Transverse occipital section at Level 1 (Fig 7) *a*, left lateral ventricle, *b*, tumor, *c*, thalamus, *d*, third ventricle

*Operation (Towne)*—October 31 the scalp and left temporal muscle were infiltrated with 90 c.c. of 0.5 per cent procaine, containing 0.45 mg. of epinephrine. A large bone flap was turned down to uncover the lower frontal and upper temporal cortex and the inferior end of the central fissure. The bone under the temporal muscle was widely removed. The tense dura was radially incised under the bone defect, the intention being to make a subtemporal decompression and to postpone further exploration until a second stage. The

<sup>8</sup> Dandy, W. E. Fluoroscopy of the Cerebral Ventricles, *Bull. Johns Hopkins Hosp.* 30:29 (Feb.) 1919.

temporal cortex protruded moderately through the opening in the dura. A needle introduced at a soft area well forward in the superior temporal gyrus tapped a glommatous cyst at a depth of 1.5 cm. About 15 c.c. of the typical, clear yellow fluid were obtained. This contained 480 red cells and 7 white cells per cubic millimeter and did not reduce Fehling's solution. The tension was now relieved so that the cortex could be depressed with a spoon to allow examination to a point some distance from the dural opening, but no extension of the tumor to the surface could be found. The wound was closed, and the patient, with a pulse of 90, was returned to the ward.

The epinephrin hemostasis was excellent, so that only a few of the larger vessels bled. There was pain only twice, from traction on the temporal muscle when the bone flap was broken down, and when the middle meningeal artery

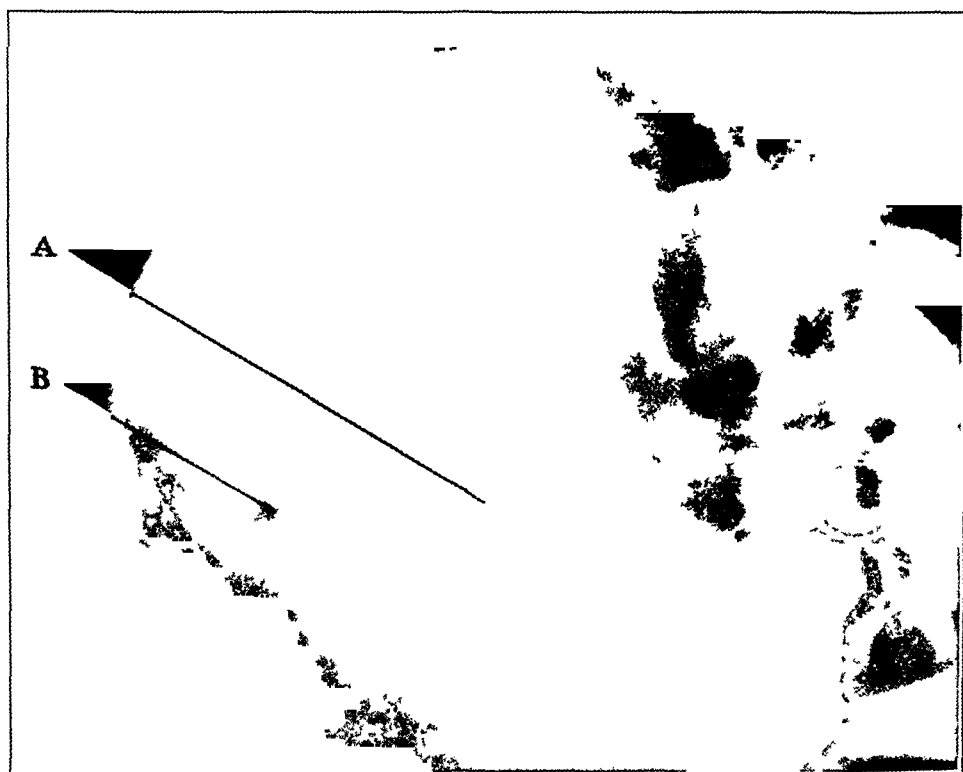


Fig. 11 (Case 4)—Tumor of left temporosphenoidal lobe compressing left lateral ventricle. *a*, air in right lateral ventricle; *b*, trephine opening in skull. Anteroposterior projection with horizontal ray, right side down.

was ligated. The intracranial pressure was far less than one expects to find in similar cases in which ether anesthesia is employed.

*Postoperative Course*—The wound healed cleanly. She was out of bed on the sixth day and was discharged from the hospital on the eighteenth day. She had no nausea, dizziness or epileptic attacks. Several times she complained of severe headache of short duration, and at these periods the decompressed area was full and tense. At all other times the hernia was soft and only slightly raised. At discharge, the optic disks were still elevated from 1.5 to 2 diopters. When last seen, December 5, her memory appeared to be improving, and she was much brighter and more responsive. The swelling of the right optic disk was entirely gone. The margin of the left disk was still hazy and

there was a scarcely measurable swelling. Vision was right 15/30 left 15/20 as before operation—in unexpectedly good result.

Credit for the localization of this tumor must be given to the ventriculogram. The definite clinical finding was loss of memory. There was a clear history of disorientation and an indefinite history of aphasia, but neither could be demonstrated by tests. Without the ventriculogram the diagnosis was a tumor of a frontal lobe. The therapy would probably have been a subtemporal decompression or a combined decompression and bone flap operation on the right side, as the patient was right-handed. This might have saved vision, but it would not have made possible the evacuation of the cyst. With the tumor located in the left temporal lobe, it can now be aspirated whenever necessary and it can also be attacked with massive roentgen-ray doses if that appears desirable.

From the point of view of roentgen-ray technic it is interesting to note that in Cases 3 and 4 lateral projections gave only partial information while anteroposterior projections with the horizontal ray revealed the unilateral location of the in-

#### SUMMARY

By means of ventriculograms three cases of obstructive hydrocephalus in infants were diagnosed as being caused by occlusion of (1) the foramina of Magendie and Luschka (2) the aqueduct of Sylvius and (3) the right foramen of Monro. No other method could have thus shown the exact location of the obstructions. In all three the disease was so far advanced that the cortex was markedly thinned and secondary enlargement of the head had followed. Large amounts of cerebrospinal fluid, from 500 to 1,500 c.c., were replaced by air. In two cases new interventricular passages were made, but, through the operations were fairly well borne, the hydrocephalus was not cured and both patients died at a later date. The third patient died of shock following extirpation of a choroid plexus. The results emphasize Dandy's statement that these cases must be diagnosed by ventriculogram and operation must be performed before the head enlarges. He has shown that before the ventricles are greatly dilated the points of obstruction can be successfully attacked. Even when the diagnosis is delayed, it is more satisfactory, if forced by the hopeless outlook to do something, to try to correct the cause of the condition rather than to attempt to palliate the result by a drainage operation.

Dandy has reported two cases of cerebral tumor, one occipital, the other frontal, which were localized by the ventriculogram after other methods had failed. In my fourth case the symptoms suggested a frontal lobe tumor, right or left. The ventriculogram showed that the left lateral ventricle contained no air. At operation, a cystic glioma was



found in the left temporosphenoidal lobe. The patient was dismissed in a much improved condition.

From this limited experience, it appears that the replacement of ventricular fluid by air is harmless and of great value in the early stages of internal hydrocephalus, and that it is the essential diagnostic method in the localization of tumors lying in silent areas of the cerebrum.

# CHANGES IN THE MORPHOLOGY AND FUNCTION OF THE BONE MARROW AFTER SPLENECTOMY\*

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## INTRODUCTION

In this series of investigations on the bone marrow I have had a two-fold purpose—first to devise a new method of studying marrow that would secure a connected picture of changes in the marrow, and second to observe the function of the marrow after the removal of the spleen. The need of this investigation was suggested to me by my findings in a previous study<sup>1</sup> of the blood changes after removal of the spleen for kala-azar.

Hitherto most observations on the function of the marrow have been limited to single isolated specimens usually secured at necropsy or by etherizing laboratory animals. A single specimen of bone marrow gives insufficient evidence. An adequate conception of the behavior of the marrow can be secured only by frequent observations (on the same person or laboratory animal) at regular intervals and over a period sufficiently long to afford a connected record of changes throughout the entire course of the disease. One of the most difficult factors in connection with the technic is adequate experimental control. I have, therefore, given special attention to the development of a system of rigid experimental control.

It should be stated that my reason for undertaking this study of the marrow and for giving special attention to the early period after splenectomy is the fact that previous investigators, notably Pearce and Krumbhaar,<sup>2</sup> have reported practically negative findings for the first six months. They noted definite marrow changes, however, after from six months to one and one-half years. Their study of the marrow after splenectomy still constitutes the most complete contribution on the subject.

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\* Abridgment of thesis submitted to the Faculty of the Graduate School of the University of Minnesota in partial fulfilment of the requirements for the degree of Master of Science in Surgery, June, 1921. The original thesis contained a complete review of the literature, with a bibliography, eight charts, seven photomicrographs, three drawings in color, and thirteen protocols, none of which are included here.

† This work was done in the Division of Experimental Surgery and Pathology.

1 Johnstone, E. M. A Study of Blood Changes in Kala-Azar After Splenectomy, *China M. J.* **32** 505-513, 1918.

2 Pearce, R. M., Krumbhaar, F. B., and Frazier, C. H. The Spleen and Anemia, Experimental and Clinical Studies, Philadelphia: J. B. Lippincott 1918.

The fact that the most severe stage of anemia and most instances of recovery therefrom occur during the first six months after the removal of the spleen naturally leads us to expect corresponding marrow changes during this period. Pearce and Krumbhaar, failing to find such marrow changes during the first six months, concluded that the changes observed later could not be considered compensatory to an anemia which had already cleared up. They stated their reasoning thus:

If the hyperplasia of the bone marrow is compensatory to increased blood destruction or decreased blood formation one would expect definite hyperplasia during the earlier period, during the first three months after splenectomy at a time when the anemia is evident and repair is taking place, and not six months to a year and a year and a half when the blood picture is normal. It is therefore impossible, on account of the late development of the hyperplasia of the marrow, to explain its occurrence as compensatory to the anemia following splenectomy.

Contrary to these observations by Pearce and Krumbhaar and their associates, my study of marrow changes after splenectomy has revealed definite early changes. The differences in our findings are, I believe, due to variations in methods. First, there is a fundamental difference in the method of experimental control. They used the marrow of one animal to control changes in another animal, whereas I controlled postsplenectomy changes by a control specimen of marrow taken from the same animal before splenectomy. I also studied a series of non-splenectomized animals subjected to exactly the same conditions as a subsidiary control. Secondly, it is important to note that Pearce and Krumbhaar and their associates made no observations during the fourth and fifth months after splenectomy. This is significant because it was during these months that I observed maximal marrow changes. Thirdly, my method obtained a connected picture of marrow changes not possible by the study of single and isolated specimens of marrow taken from various animals. Fourthly, in my method the rib marrow was studied instead of the marrow of the central third of the femur. The rib marrow shows marrow changes earlier than the marrow of the central third of the femur.

It is evident that the function of the marrow during the first few months after splenectomy is the crux of the problem. If during this period there is hyperplasia and hyperactivity, postsplenectomy anemia is due to no fault of the marrow but, rather, to some destructive factor, possibly an hemolysin, which is set into activity by removal of the spleen. Since the question of the function of the marrow, especially during the period immediately following splenectomy, is of sufficient importance to warrant further investigation, I have ventured to continue the study of the problem by devising a new method and by giving more emphasis to the accomplishment of rigid experimental control.

## EXPERIMENTS

The schedule for this investigation of the marrow and its relation to the spleen involved the collection of data in a form which would allow the analysis and comparison of ten factors. Four of these referred to the marrow—erythropoiesis, leukopoiesis, vascularity, and density of marrow cells. Four referred to the blood stream—the hemoglobin content, the erythrocyte count, the leukocyte count, and a differential study of the blood cells. Two referred to the laboratory animal in a general way—its weight at regular intervals and parallel notes on its general condition such as the healing of the operative wounds and the absence or presence of any influence that might affect the marrow even in a minor way.

All data were collected simultaneously just before taking each specimen of marrow. This parallelism of observations not only justified comparison of data but also contributed to a much more comprehensive knowledge of what occurs after removal of the spleen than could be secured by studying the marrow alone.

Five series of experiments were carried through. Series 1, 2, 3 and 4 failed to accomplish exact experimental control. My report is based largely on the findings by the new method of experimental control used in the experiments in Series 5. Brief references will be made to the first four series because they bring out certain points which are important when studied in conjunction with the findings in Series 5.

**Series 1** The marrows from the tibias of twenty-five rabbits, thirteen splenectomized and twelve nonsplenectomized, for periods up to fourteen months after splenectomy, were studied. The marrows of the splenectomized rabbits were controlled by the marrows of the nonsplenectomized rabbits.

**Series 2** The marrows from the femurs (central third) of fourteen dogs, eight splenectomized and six nonsplenectomized, for a period of more than one year after splenectomy, were studied. In this series also the splenectomized animals' marrows were controlled by the nonsplenectomized animals' marrows.

**Series 3** The marrows from the femurs of two goats, of the same age, one splenectomized when 3 weeks old, and one nonsplenectomized, for a period of fifteen months after splenectomy were studied. In this series also the nonsplenectomized goat was a control for the splenectomized goat.

**Series 4** The marrows from the central third of the left femur of each of six dogs, three splenectomized and three nonsplenectomized, taken at the end of the experiment, were compared with the marrows taken as controls before splenectomy from the center of the right femur from each of the same dogs.

Series 5 A The marrows from the ribs, taken at frequent intervals from fourteen dogs, eight splenectomized and six nonsplenectomized, operated on under ether anesthesia and by sterile technic, were studied

Series 5 B The marrows from the ribs of four dogs, two splenectomized and two nonsplenectomized, were studied in the same manner as in Series 5 A, except that cocaine anesthesia was used instead of ether. The details of the satisfactory methods (Series 5 A and B) follow

#### METHOD OF OBTAINING RIB MARROW SPECIMENS

A piece of rib, 4 cm long, was removed from a point midway between the spine and sternum. This specimen, removed before splenectomy, from a healthy and apparently normal dog, constituted the control for subsequent pieces of rib removed from the same animal at regular intervals after splenectomy. The six dogs in Series 5 A, not splenectomized and used as additional controls, had exactly the same treatment, including the rib resections and abdominal incisions, except that after the spleen was delivered outside the abdomen and traction and trauma were exerted, such as were estimated to equal those of splenectomy, the spleen was returned to the abdomen and the wound closed. Thus each specimen of marrow was controlled by a specimen from the same animal before the splenectomy, as well as by the similar series of rib resections from nonsplenectomized animals. Test examination of many specimens from similar parts of the ribs has proved that the marrow from the same relative position of several ribs from the same animal is very similar in cell character and activity.

By this method as many as nine specimens of rib marrow from a single animal were secured at intervals of from two weeks to several months during a total period of fifty-four weeks' observation. Thus in Dog 32 the first rib marrow specimen, removed before splenectomy, was the control. The second specimen was removed two weeks after splenectomy, the third, five weeks after, the fourth, nine weeks, the fifth, seventeen weeks, the sixth, twenty-nine weeks, the seventh, forty-one weeks, and the eighth, fifty-four weeks. In connection with this experiment, a nonsplenectomized dog was put through exactly the same routine rib resections with the same intervals between resections, as an additional control.

Before each operation the blood was examined for the number of leukocytes and erythrocytes, and the hemoglobin estimation. Similarly, before each operation, a record was made of the animal's general condition, the healing of former wounds, and the weight. In three experiments of Series 5 A, blood smears were also made at frequent intervals to check the types of blood cells and compare them with the cells seen in the marrow of the same animals. At the end of the experiment the animals were etherized and necropsy was performed in

order to insure that they were not affected by disease or any factor except absence of the spleen

Great care was taken to rule out animals in which a complication might introduce an additional factor affecting the marrow. Of a series of thirty-nine rabbits, fourteen were excluded from consideration owing to wound infection, "snuffles," pregnancy and so forth. Empyema, pregnancy and suppurative cystitis of unknown cause required the rejection of three dogs. In a few cases the experiments were continued in animals in which a very slight and superficial stitch infection occurred. In these cases the presence of such a factor was noted and clearly marked on the charts so that due significance might be attributed to the condition. These wounds healed readily, however, and if they were of significant influence on the marrow function it could be for a brief period only, and probably at the most no more than one marrow specimen was affected.

The animals were kept on a uniform diet throughout the experiment, except two animals who became so thin and anemic at one period shortly after splenectomy that for a short time they were given meat and milk in addition to the regular diet.

None of the animals finally retained as satisfactory for marrow study died because of sickness. Every animal when etherized, except Dog 376, appeared to be as healthy as when the experiment was begun in June 1919. This animal appeared perfectly healthy up to May 12, 1920, when he died suddenly. Necropsy showed acute meningitis. Five marrow specimens, the last of which was taken April 8, were retained because the animal was healthy for a month after these specimens were taken. The final marrow specimen was not included in the report because it was probably affected by the terminal febrile infection.

At necropsy not only were numerous specimens of femur and rib marrow taken, but also lymph nodes and hemolymph nodes were preserved for study. A general search was made for any pathologic condition, special attention being given to the chest. In no case was there any sign of empyema or even adhesions from pleurisy.

A separate series of animals was studied, using cocaine anesthesia, in order to determine whether the anesthetic is a complicating factor.

#### PREPARATION OF RIB MARROW SPECIMENS FOR MICROSCOPIC STUDY

A piece of rib, approximately 4 cm. long, is removed midway between the spine and the sternum. It is advisable to remove a subsequent specimen of rib marrow from the opposite side of the chest, or at least one or two ribs distant from the previous site of rib resection, in order to insure the absence of local inflammatory reaction in the region from which a new marrow specimen is to be taken.

The rib marrow specimen is held very firmly against a block of wood and is cut into five pieces with a sharp, fine saw, with care not to squeeze out the marrow or injure it, except at the site of actual cutting. The pieces from each end of the specimen are thrown away because at these points the marrow cells are crushed out of their normal relationship at the time of operation. Three pieces of rib, approximately 1 cm long, are thus secured for fixation and section.

Several methods were tried before satisfactory rib marrow sections were prepared by the following steps:

**Specimen** A small specimen is placed in Zenker's solution (without glacial acetic acid) for twenty-four hours. The specimen is washed in running water for twenty-four hours. The specimen is placed in 5 per cent nitric acid and is changed daily until the block is soft enough to be cut. This requires for from three to seven days. If the rib has a very thick, hard bone cortex, a 10 per cent solution of nitric acid is necessary. The specimen is washed in running water for twenty-four hours. An attempt to facilitate the process of washing out the acid by use of sodium bicarbonate solution results invariably in "hazy" or "muddy" sections. Ordinary tap water is found to give the most satisfactory results.

The specimen is placed consecutively in 80 per cent alcohol for twenty-four hours, 95 per cent alcohol for twelve hours, absolute alcohol for three hours, equal parts of absolute alcohol and cedar oil for one hour, cedar oil for one hour, chloroform (two changes) for one hour, equal parts of chloroform and paraffin for one hour, and paraffin (two changes) for two hours. The specimen is then embedded.

**Sections** The section is made 7 microns thick. For staining, the section is run through toluene and graded alcohol to water (about two minutes in each solution) as follows: toluene (two changes), absolute alcohol (two changes), 95 per cent alcohol, 70 per cent alcohol, 50 per cent alcohol, and distilled water.

The section is left about five minutes in 5 per cent eosin. The tendency is to overstain with eosin. The section is washed through two waters. The section is stained with polychrome methylene blue (Goodpasture's) for about two minutes. The section is immersed in 95 per cent alcohol (two changes) for about two minutes each. It is then examined under the microscope. If it is too blue, it is again washed in 95 per cent alcohol. If it is not blue enough, it is returned to the water and restained. The section is washed with absolute alcohol for about two minutes, and xylene or toluene for about two minutes. The section is mounted with Canada balsam, after which it is ready for histologic study.

## METHOD OF RECORDING OBSERVATIONS ON BONE MARROW

Observations involving a close microscopic study of the marrow with oil immersion lens were essentially processes of comparison. Pathologic marrow was compared with normal, hyperactive marrow with a normal or sluggish marrow, very vascular marrow with relatively slightly vascular marrow, and a marked density of marrow cells was numerically compared with a marrow containing a few scattered marrow cells amid masses of fat cells.

In order to compare and record marrow findings, the following system of grading activity, vascularity, marrow cell density, and so forth, was adopted:

**Erythrogenesis.** Grade 1 is the most sluggish erythrogenesis observed. It consists of a field in which most of the cells are primitive cells, myeloblasts, myelocytes, and fat cells, with a few scattered normoblasts and megaloblasts as evidence of erythrogenesis. Grade 4, on the contrary, indicates the most active type of erythrogenesis observed in any rib marrow. Grades 2 and 3 are intermediate between Grade 1 and Grade 4.

By much practice it finally proved possible to grade specimens of marrow so that the gradings of the same specimen varied no more than one half of one grade, even though the examinations were made weeks apart, so that each subsequent grading was unprejudiced by recollection of the previous grading.

**Leukogenesis.** Gradings of leukogenesis were made in exactly the same manner as of erythrogenesis.

**Vascularity.** Grade 1 is a marrow with only a few small capillaries moderately filled with erythrocytes. Grade 4 is a marrow containing numerous capillaries and sinuses congested with erythrocytes. Grades 2 and 3 are intermediate between Grade 1 and Grade 4.

**Cell Density.** Grade 1 of marrow cell density represents a rib marrow with small islands of marrow cells with considerable fat, the bone cortex and bony trabeculae and septums which divide the marrow compartments in the rib are quite thick. Grade 4 represents a rib marrow containing large islands of dense marrow cells with little or no fat, often these large islands of marrow cells become confluent and the bony septums become fewer and thinner. The bone cortex also undergoes a change and is thinned out and honeycombed by numerous new small islands of marrow cells. Grades 2 and 3 constitute intermediate grades between Grade 1 and Grade 4.

**General Activity.** General activity of marrow is estimated by computing the mean of four factors: erythrogenesis, leukogenesis, vascularity of the marrow, and density of marrow cells. Thus, for example, if in a given specimen of marrow, erythrogenesis is estimated as Grade 3, leukogenesis, Grade 2, vascularity, Grade 2, and



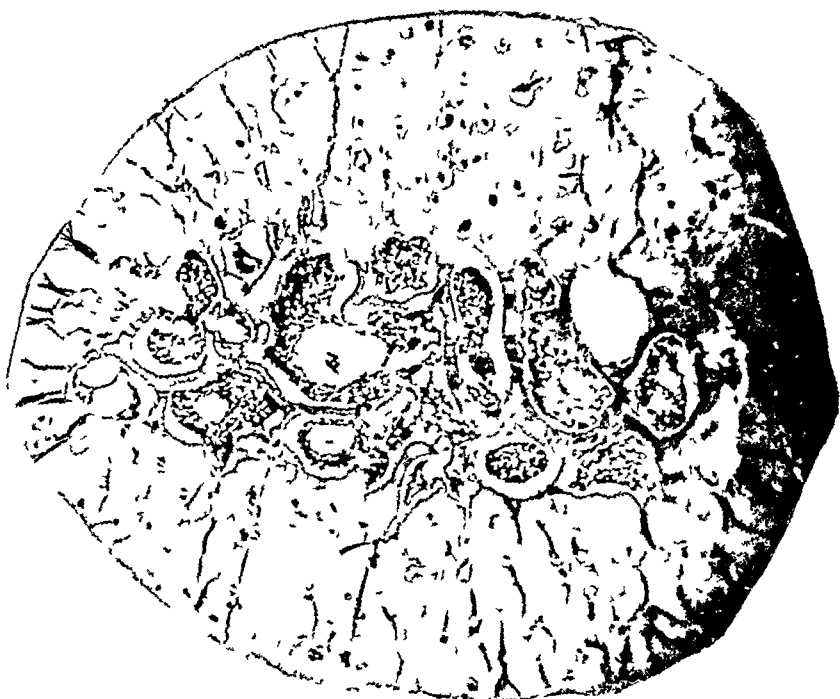


Fig 1 (D 208) —Specimen of sluggish marrow, characterized by the large amount of fat, the thick bone cortex, the thick bony septums, and the small islands of marrow cells which honeycomb the bone cortex,  $\times 18$

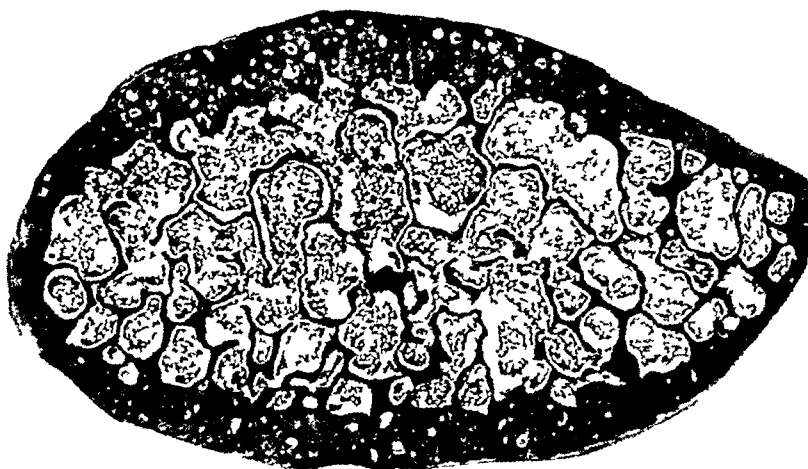


Fig 2 (D 239) —Specimen of moderately active rib marrow, characterized by the large amount of fat (white), few marrow cells, the thin bone cortex and thin bony septums which separate the islands of marrow cells,  $\times 18$

density of marrow cells, Grade 3, the general activity, by averaging the four grades would be computed to be Grade 2.5

This is a purely arbitrary method of recording data, but if the observations are all made by one investigator who carefully maintains the same grading throughout the study, the figures secured furnish a convenient and accurate basis for comparison of different marrow specimens. Such a system of records also permits plotting curves representing marrow activity, and so forth. It thus becomes possible to present the results of the experiments in a graphic form that is definite and readily comprehended.

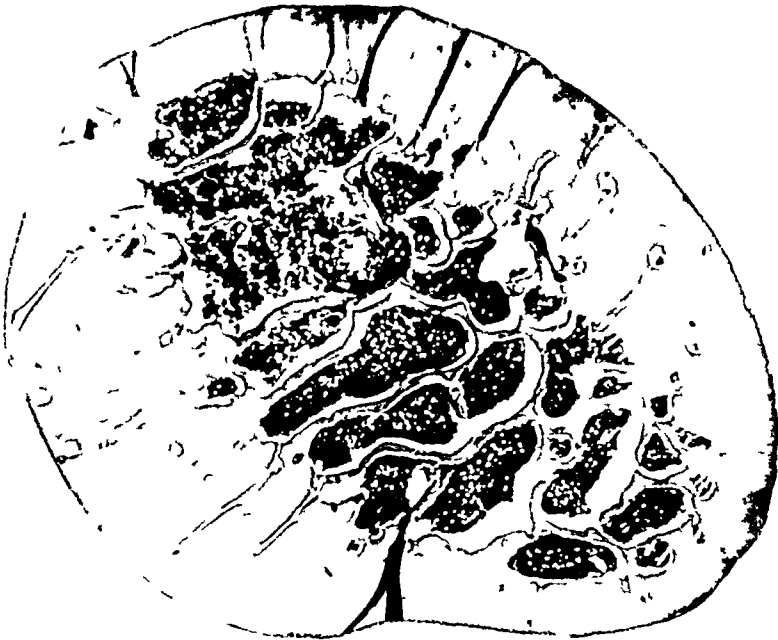


Fig 3 (D 232)—Specimen of very active rib marrow, characterized by few fat cells, many normoblasts and megaloblasts whose deeply staining nuclei give a dark color to the photomicrograph, and large islands of marrow cells which are confluent in places,  $\times 18$

Nine curves were made for each of the ten splenectomized and eight nonsplenectomized dogs (Series 5 A and 5 B). The nine curves plotted for each animal experiment form three groups. Group 1 consists of five curves—erythrogenesis, leukogenesis, vascularity, cell density, and general activity. This group of curves, therefore, indicates the condition of the marrow. Group 2 consists of three curves—the white cell count, the red cell count, and the hemoglobin estimation. These show the parallel blood findings. Group 3 consists of one curve and notes which give the animal's weight, general health, condition of the wound, and the findings at necropsy, all being made to parallel the marrow and blood observations.

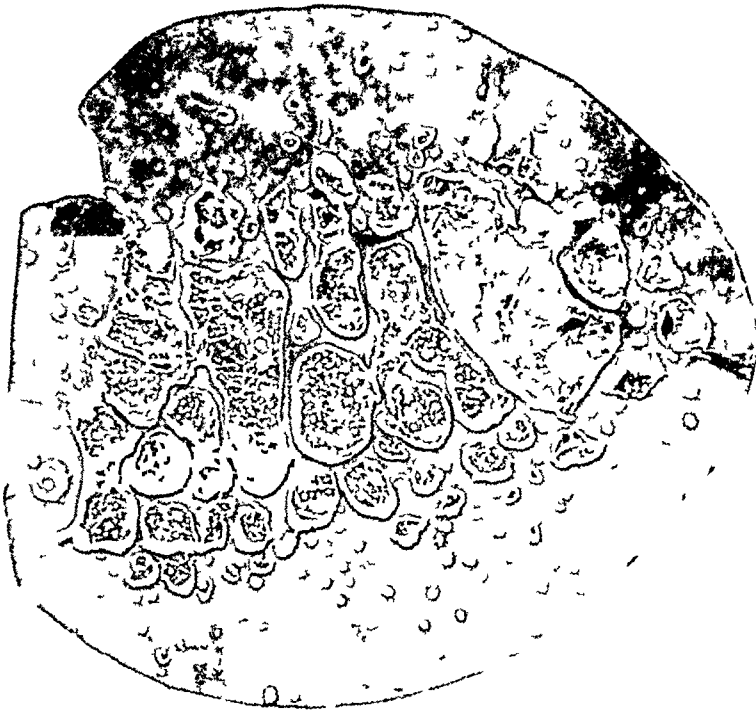


Figure 4



Figure 11

Fig 4 (D 230) —Specimen of moderately active rib marrow, showing the process of formation of new marrow cells in the bone cortex,  $\times 18$

Fig 11 (D 230) —Specimen of rib marrow of a dog taken two weeks after splenectomy, characterized by the presence in the marrow of myelocytes, meta-myelocytes, mature polymorphonuclears and the primitive undifferentiated mother cells,  $\times 600$



Figure 5



Figure 6

Fig 5 (G 82) —Specimen of femur marrow of a splenectomized goat taken fifteen months after splenectomy, characterized by numerous eosinophilic myelocytes and active erythrogenic groups,  $\times 600$

Fig 6 (G 79) —Specimen of femur marrow of a nonsplenectomized goat, characterized by a framework of marrow with large fat spaces and few groups of erythrogenic marrow cells,  $\times 600$



Figure 7

Fig 7 (D 32) —Specimen of rib marrow of a dog taken nine weeks after splenectomy, characterized by large spaces which are relatively inactive and others which are very active,  $\times 200$

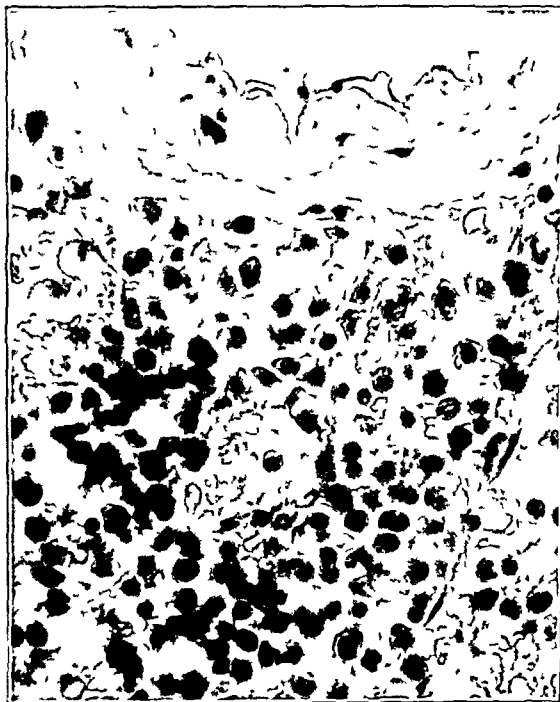


Figure 8

Fig 8 (D 32) — Specimen shown in Figure 7 at a higher magnification, showing the mixed erythropoiesis and leukopoiesis,  $\times 600$

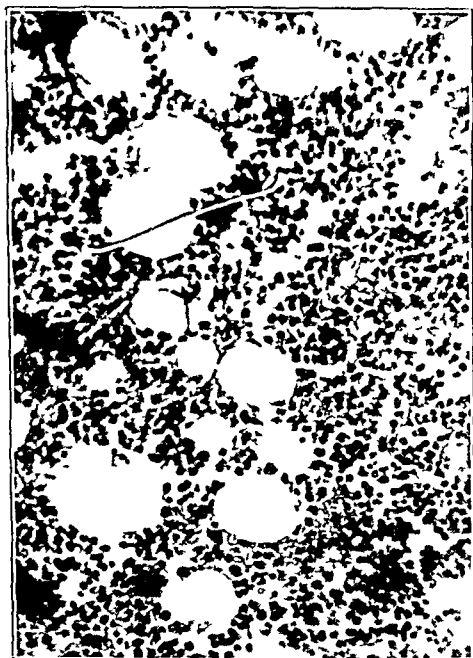


Figure 9

Fig 9 (D 32) —Specimen of rib marrow of a dog taken seventeen weeks after splenectomy, characterized by numerous normoblasts indicating active erythropoiesis,  $\times 200$



Figure 10

Fig 10 (D 32) — Specimen shown in Figure 9 at a higher magnification, showing the maximum degree of activity after splenectomy,  $\times 600$

## A STUDY OF THE MARROW OF VARIOUS ANIMALS

It has been customary to use one animal as a control for another animal in a study of the marrow. For instance, one of two dogs is splenectomized. At the end of a certain period, six months, for example, the two animals are killed by ether, and their marrows, usually the central third of the femur marrow, are compared. If the marrow of the splenectomized animal is much more active than that of the nonsplenectomized animal, it is assumed that splenectomy causes an increase in marrow activity.

In my first three series of experiments, I undertook to use one animal to control another, but certain observations led me to suspect that the marrows of apparently healthy and normal animals differ markedly. Therefore, I determined to make a special study of the question.

Comparisons were made of gross and microscopic specimens of the marrows from the center of the femurs of ten healthy dogs, all approximately of the same age and all adapted to laboratory conditions, on a standard diet. The marrows of five dogs were graded 1 to 1.5, of three, 2 to 2.5, and of two, 3 to 3.5. Thus, in a series of ten healthy normal dogs picked at random, there was a very marked difference in the marrows. It is apparent that one dog's marrow cannot be used as a control for that of another in laboratory experiments, and when it is considered that the dogs used for experimental purposes are of the most varied mongrel breeds, it is not surprising that their marrows also vary in character.

A similar study was made of the marrow of the tibias of twelve rabbits. The erythrogenic activity of the marrows of two rabbits was graded 1, of six 2, and of four 2 to 3. The leukogenic activity of the marrows of seven rabbits was graded 1, of the marrow of one rabbit, 1 to 2, of the marrows of two rabbits, 2 to 3, and of the marrow of one rabbit, 3.

These findings show how varied are the marrows of individual rabbits, even though many of these were from the same litter and grew up under identical environmental conditions, and that it is unsafe to use one rabbit to control another in an experimental study of the marrow.

Specimens of marrow from the ribs midway between the spine and sternum were taken from fourteen healthy normal dogs. The erythrogenic activity of the rib marrows of nine dogs was graded 1, of two 1.5, and of three 2. The leukogenic activity of the rib marrows of seven dogs was graded 1, of two 1.5, of three 2, and of two 2.5. Because these experiments demonstrated the fallacy of controlling experiments on the marrow of one animal with the marrow of another,

I devised a new method of control as used in Series 5 of the experiments. The essential feature of this method is the removal of a specimen of rib marrow before splenectomy for a control of successive specimens taken from the same animal after splenectomy.

#### HISTOLOGY OF THE RIB MARROW

In all main respects I agree with the admirable description of marrow cell groups given by Pearce and Kumbhaari,<sup>2</sup> whose groupings were a modification of those previously made by Bunting.<sup>3</sup> Valuable descriptions of the morphology of the cells in the marrow were found in Gruner's<sup>4</sup> "The Biology of the Blood Cells."

Marrow cell groups are usually mixed erythrocytic and leukogenic. Very rarely a purely erythrocytic or purely leukogenic group is found, but commonly in groups of marrow cells erythrocytic or leukogenic predominates so largely as to justify the description of the group as essentially one or the other. After a close study of the function of the marrow of the femur and rib of the same animal I have been convinced that leukogenesis is more active in the rib.

Because the rib marrow quickly shows changes in activity and reveals small degrees of change it is well adapted for study. The central third of the femur marrow, on the other hand, is tardy in showing changes in activity, and only after quite marked changes in the marrow function elsewhere is there a perceptible modification of the marrow of the central third of the femur. For these reasons the rib marrow is a better index of change than the femur marrow.

My observations on the marrow of the dog did not lead me to believe it to be a seat of active production of lymphocytes. Because Gulland and Goodall<sup>5</sup> describe very active lymphogenesis in some marrows, I made a special study of this matter. Specimens of spleen, lymph glands, hemolymph glands and ribs were taken from the same animal. Direct comparison of similarly stained specimens was made between known lymphocytes in the spleen and glands with lymphocyte-like cells in the marrow, the micrometer was frequently used to compare exactly the relative sizes. By such a direct comparison of cells in specimens arranged under adjacent microscopes, I was convinced that a few lymphocytes occur in the marrow and are, apparently, generated there. A significant degree of lymphogenesis was observed, however,

3 Bunting, C. H. Experimental Anemias in the Rabbit, J. Exper. Med. 8: 625-646, 1906.

4 Gruner, O. C. The Biology of the Blood Cells, with a Glossary of Hematological Terms, Bristol, J. Wright and Sons, 1913.

5 Gulland, G. E., and Goodall, A. The Blood, a Guide to Its Examination and to the Diagnosis and Treatment of Its Diseases, Edinburgh, W. Green and Sons, 1914, p. 96 and p. 110.

in isolated marrow specimens of two animals only. It appears that lymphogenesis can occur in the marrow and that a slight degree may be common, but a noticeable active lymphogenesis is rare.

One very interesting phase of the histology of the marrow is the method by which the rib marrow increases its capacity. This increase is accomplished by several changes which may operate separately or all together. The earliest and most common method is for marrow cells to replace the fat cells, which are abundant in a sluggish marrow. If there is a continued demand for hyperplasia and hyperactivity of the rib marrow beyond that which can be met by simple replacement of fat cells by marrow cells, an enlargement of the rib marrow cavity is produced by a thinning of the bone cortex and the bony septums which divide the rib cavity into compartments. This process consists of not only a general thinning of the bone cortex of the rib, but also of a "honey-combing" by small islands of marrow cells which become larger as hyperplasia increases. When specimens were prepared from rib resections soon after splenectomy, it was necessary to use a sharp saw and cut through quite a hard, thick bone cortex, but as hyperplasia increased in the rib marrow, the rib specimens became changed so that at times it was even possible to cut the rib sections with a knife instead of a saw, and even macroscopically the thinning of the bone was evident.

As the rib marrow space was thus increased in size, there were simultaneous changes in the character of the marrow cells therein. In a sluggish marrow most of the cells are primitive cells, myeloblasts and myelocytes, normoblasts, megaloblasts, and metamyelocytes are few. But as the marrow becomes active there is a greater preponderance of these intermediate forms. Large numbers of megaloblasts and normoblasts mean an active erythropoiesis. Numerous metamyelocytes fringed by more mature leukocytes are likewise interpreted as a sign of active leukogenesis. When a series of eight or nine marrow specimens, taken at regular intervals during a year or more after splenectomy, is studied under the microscope so as to trace the marrow changes step by step, it is of fascinating interest to observe how hyperplasia and hyperactivity are accomplished at the same time (Figs 1 to 11).

#### DETAILED SUMMARY OF FINDINGS

A summary of the observations regarding the influence of splenectomy on the bone marrow is essentially an analysis of the charts (Figs 12 to 20) on which the data have been concentrated. One of the series of protocols has been appended as a typical illustration of the experimental procedure and the manner of recording data.

*Changes in the Erythrogenic Function of the Marrow After Removal of the Spleen of a Normal Animal*—If the findings relating to the rib

marrow changes in the six splenectomized animals of Series 5 A (operated on under ether anesthesia) are correlated, the average erythro-genic reaction may be summarized, as in the accompanying table and in Figure 12

1 There is, on the average, a latent period of four weeks before an increase in erythrogenic activity is observable

2 Increased erythrogenesis, first observable about four weeks after splenectomy, attains its maximum degree of activity after from eight to twelve weeks

3 Maximal erythrogenic activity, attained about twelve weeks after splenectomy, persists practically unabated for about twelve weeks

4 Hereafter the production of red blood cells decreases gradually until a period varying from twenty-eight weeks to one year or more

ERYTHROGENESIS IN THE MARROW OF SIX DOGS AFTER SPLENECTOMY

	D 32	D 230	C 981	D 207	D 108	D 979	Average
Time before observable increase in erythro-genesis	0 to 9 weeks	2 to 4 weeks	2 to 4 weeks	5 to 9 weeks	8 to 12 weeks	0 to 2 weeks	About 4 weeks
Time when maximal eryth-ro-genesis is reached	17 weeks	8 weeks	8 weeks	13 weeks	13 weeks	2 weeks	8 to 12 weeks
Duration of maximal eryth-ro-genesis	6 weeks	20 to 22 weeks	9 to 12 weeks	6 to 8 weeks	12 to 20 weeks	15 to 20 weeks	12 weeks
Time when erythrogenesis has decreased to fairly constant degree (some-what above normal)	30 weeks	*	20 weeks	33 weeks	44 weeks	†	28 or more weeks†

\* Erythrogenesis still very active on completion of the experiment at the thirty seventh week

† Erythrogenesis still very active on completion of the experiment at the forty fourth week

after splenectomy, when it reaches a more or less constant degree of activity, which, however, is still considerably above normal, that is, above the degree of erythrogenesis observed in the marrow of the same animal in a specimen removed before splenectomy

5 Increased erythrogenesis is observable in the marrow for a period of four weeks or more before any reduction in the anemia following splenectomy is evident. This is graphically illustrated by the respective curves on the charts (Figs 13, 14, and 17), the erythrogenesis curve rising at times in advance of the hemoglobin and erythrocyte curves

6 A further comparison of erythrogenesis with other factors, which were studied at the same time, shows certain very interesting parallelisms. On the one hand, erythrogenesis, marrow vascularity, and marrow cell density simultaneously increase, and on the other hand, the hemoglobin, the red cell count, and the animal's weight form a group with curves running remarkably parallel courses, first downward, during the development of the anemia, and then upward until they reach or exceed a normal level



*Changes in the Leukogenic Function of the Marrow After Removal of the Spleen of a Normal Animal*—Three of the six animals whose spleens were removed under ether anesthesia showed a spectacular increase in marrow leukogenesis. This reaction, occurring in only 50 per cent of the animals operated on under ether anesthesia, occurred immediately, and lasted only for from two to five weeks after splenectomy.

If in conjunction with the foregoing observations of the rib marrow the leukogenic reaction in the marrow of the tibias of twelve splenectomized rabbits, studied after the effect of ether anesthesia had presumably subsided, is considered I am inclined to believe that splenectomy itself is a factor in the cause of increased marrow leukogenesis. The ether used as an anesthetic for splenectomy seems to be at least a contributing factor in causing the leukogenic reaction. This question of the real cause of the spectacular increase in leukogenic activity after splenectomy will be considered more fully in the discussion which follows.

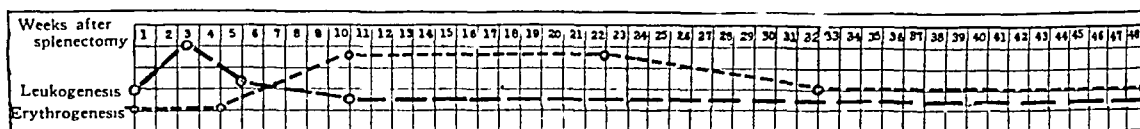


Fig 12—Average reaction of the rib marrow after splenectomy

There is an exact parallelism between the high leukogenesis in the marrow and the concurrent high leukocytosis in the blood stream (Fig 13)

*Changes in the Tibia Marrow of Rabbits Following Splenectomy*—The findings in the study of rabbit marrow were charted and retained in this report to illustrate two points: (1) the very marked differences in the marrow of apparently healthy animals so that comparisons appear to conflict in most respects, and (2) the increased leukogenesis in the marrows of the twelve splenectomized rabbits during the first few months after splenectomy when compared with the marrows of thirteen nonsplenectomized rabbits (Figs 19 and 20)

*Changes in the Marrow in the Control Animals*—The study of the marrows of many nonsplenectomized animals at intervals of from six to fifteen months revealed the variations from time to time in the marrows of normal animals. There is some fluctuation of the curves (Figs 15, 16, and 18) which suggests that hemopoiesis is somewhat periodic, but in general the curves run as constantly level and parallel as could be expected, considering that the observations extended through different seasons of the year and included many minor and unavoidable variations of environment.

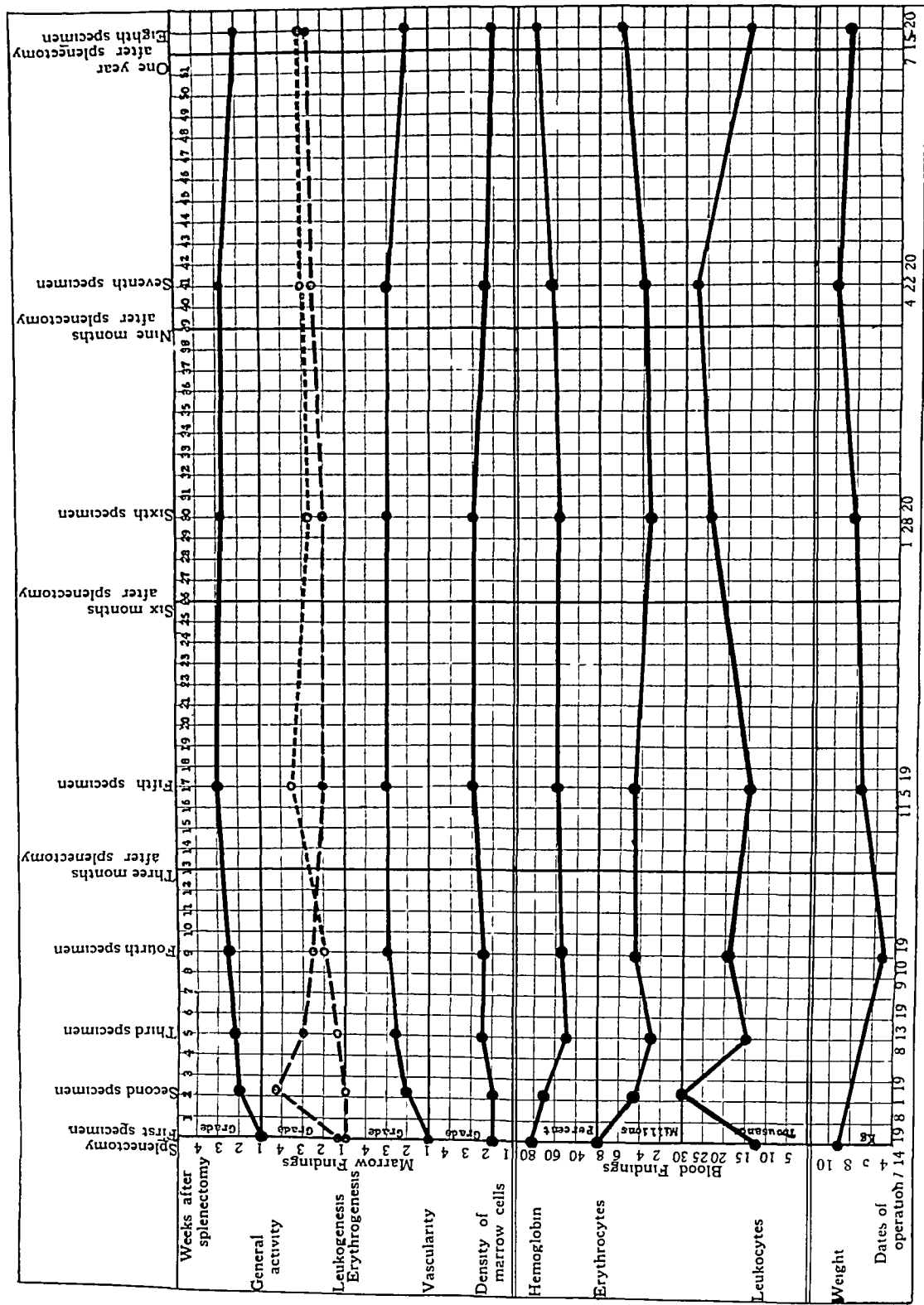


Fig 13 (D 32) —Changes in the marrow, blood, and general condition after splenectomy under ether anesthesia. Eight rib marrow specimens were removed under ether during one year. The findings are similar to those in two other experiments (D 230 and D 979). July 14, 1919, animal healthy, August 1 and August 13, very severe postsplenectomy anemia, September 10, thin and listless, wounds clean, November 5, better condition, still thin wounds clean, Jan 28, 1920, thin and rather weak, wounds clean, gradual recovery from anemia, April 22, again in good condition, wounds clean, July 15, healthy, good weight when killed. Necropsy revealed no pathologic condition.

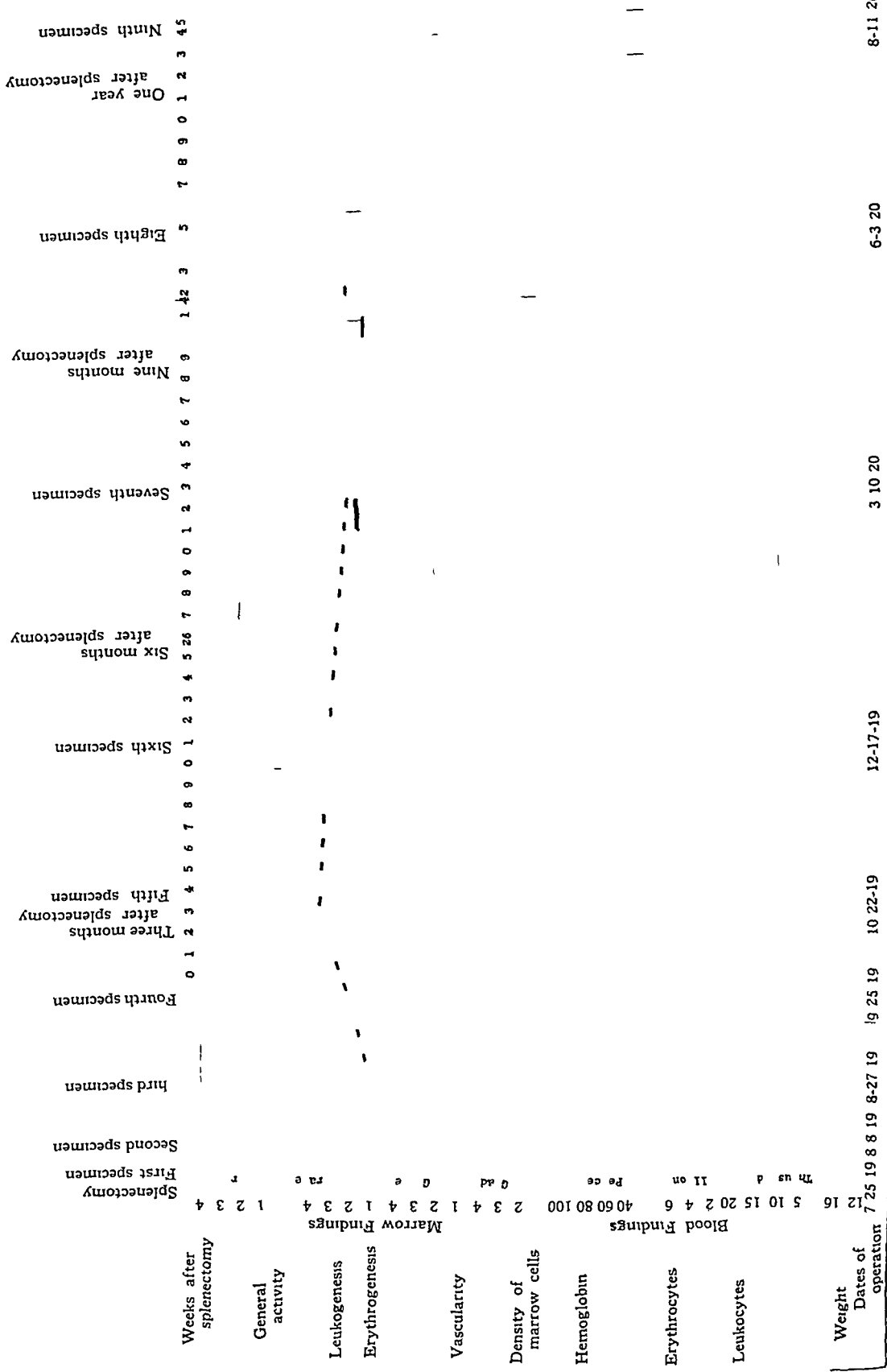


Fig 14 (D 207) —Changes in the marrow, blood, and general condition after splenectomy under ether anesthesia. Nine rib marrow specimens were removed under ether during one year and seventeen days. The findings are similar to those in two other experiments (D 208 and D 981). July 25, Aug 8 and Aug 27 1919, animal healthy, had "dog fight" night before operation, leg badly bitten September 25 good condition, wounds clean, October 22 fat and vigorous wounds clean December 17 fat and vigorous wounds clean March 10 1920 fat and vigorous wounds clean June 3 animal well wounds clean August 11 animal in excellent physical condition when killed.

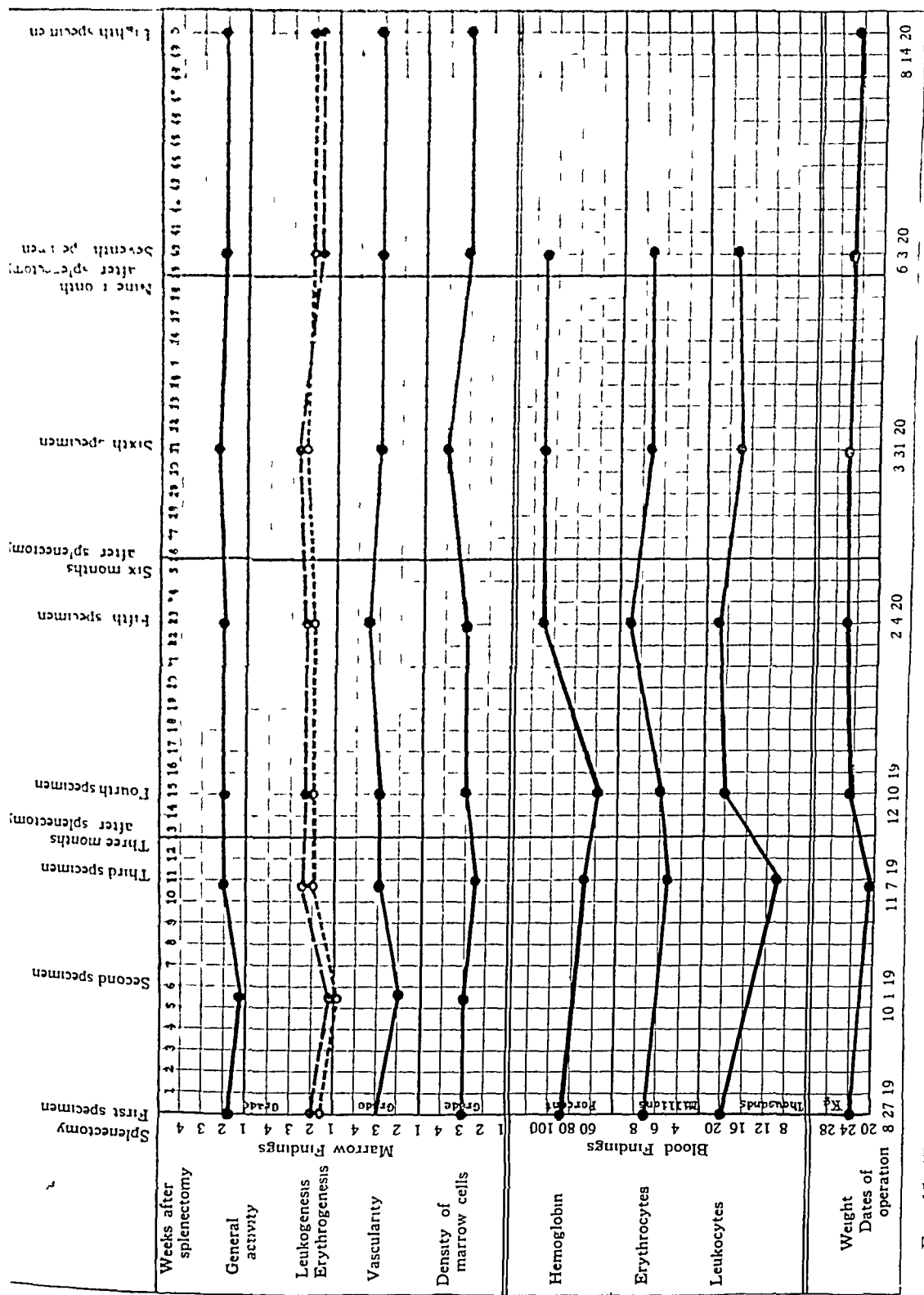


Fig 15 (D 239) —Changes in the marrow, blood, and general condition in a non-plenectomized animal. Light rib marrow specimens were removed under ether during fifty weeks. Aug 27, 1919 condition of animal, good, October 1, leg fractured, November 7, thin, wounds clean, healed, December 10, healthy but thin, special diet (milk and meat), Feb 4, 1920, fat, wounds clean, healthy, fracture united, March 31, fat and vigorous, wounds healed clean. June 3, fat and vigorous wounds healed. August 14, healthy when etherized. Necropsy revealed no pathologic condition.

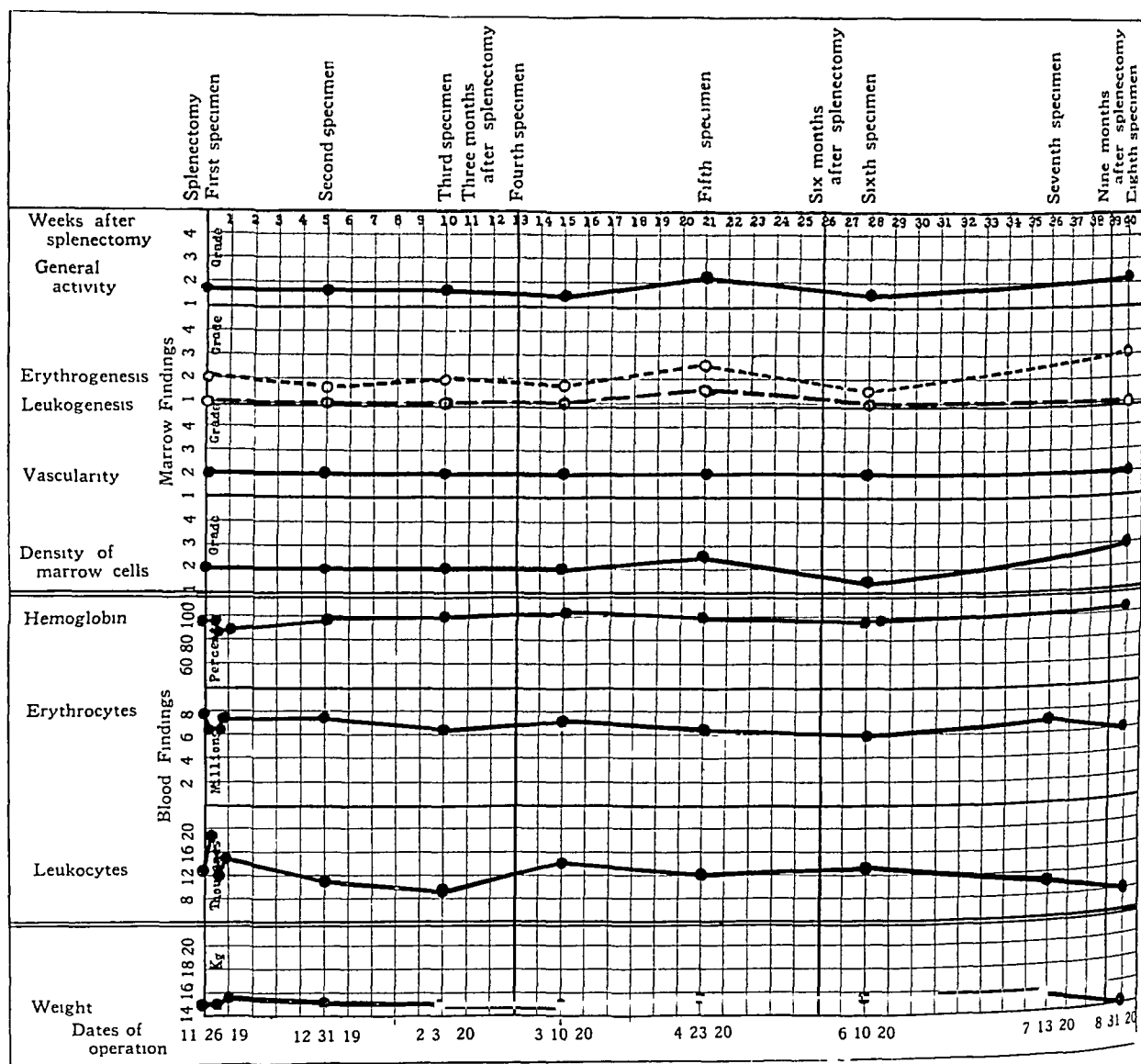


Fig 18 (D 338) —Changes in the marrow, blood, and general condition in a nonsplenectomized dog. Seven rib marrow specimens were removed under cocaine anesthesia during forty weeks. The findings are similar to those in one other experiment (D 463). Dog in healthy condition and wounds clean throughout experiment, no pathologic condition found on examination, after animal had been killed.

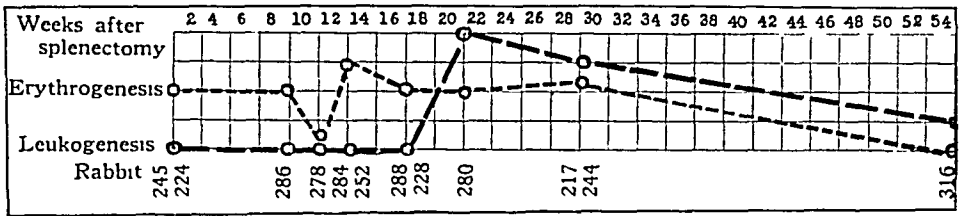


Fig 19 (Composite chart) —Changes in the marrow of the tibias of twelve non-splenectomized rabbits

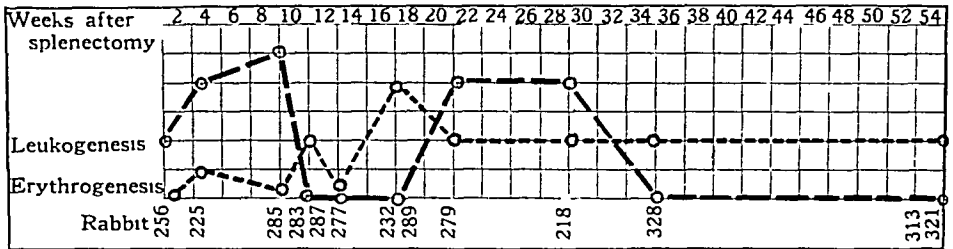


Fig 20 (Composite chart) —Changes in the marrow of the tibias of thirteen splenectomized rabbits

#### COMMENT

It has been clearly established that removal of the spleen of a healthy animal is followed by hyperplasia and hyperactivity of the marrow which begins soon after splenectomy and persists for more than a year, at least. This reaction, however, may not be primarily the result of absence of the spleen. It seems more probable that the activity of the marrow is secondary to the anemia, which follows removal of the normal spleen, and is compensatory to that anemia.

It is remarkable that a definitely increased erythrogenesis in the marrow may precede, by several weeks, any signs of a reduction of the anemia following splenectomy. It is, of course, logical that signs of increased production of red cells in the marrow should precede evidence of improvement in the blood, as cause precedes effect, but the fact that a very active erythrogenesis so long precedes a reduction of the anemia indicates that whatever destructive agent becomes active after removal of the spleen, it is so potent that its effect can be compensated only by prolonged hyperactivity and hyperplasia of the marrow.

The presence of a prompt and markedly increased marrow activity after splenectomy shows that postsplenectomy anemia is due to no fault of the marrow. The presumption is, rather, that some extramedullary factor, possibly an hemolysin, is the cause. Warthin<sup>6</sup> has suggested

6 Warthin, A. S. The Changes Produced in the Hemolymph Glands of the Sheep and Goat by Splenectomy, Hemolytic Poisons, and Hemorrhage, J. M. Research 7 435-463, 1902

that after removal of the spleen there is excessive hemolysis in the lymph nodes which often hypertrophy. Since the spleen is a main site of antibody production,<sup>7</sup> it is possible that after splenectomy the ordinary hemolytic factors act unchecked and unregulated. Whatever the cause and mechanism of postsplenectomy anemia, it is overcome by an increased activity of the marrow. It is possible that the effect of the presence of a destructive factor or the absence of a "favorable factor," normally present, gradually subsides or entirely disappears a few weeks after splenectomy so that the marrow has only to overcome a temporary disadvantage. The increased resistance of the erythrocytes after splenectomy is also a factor which probably aids in recovery from post-splenectomy anemia, especially as this increased resistance improves with the length of time after operation.

The corresponding increase in the red and white blood cells in the blood stream that accompanies an abundance of normoblasts, megaloblasts, and metamyelocytes in the marrow is strong evidence that new blood cells are being rapidly manufactured somewhere, presumably in the marrow. It occurred to me that the lymph nodes might be the site of active production of blood cells in the absence of the spleen. I, therefore, removed specimens of axillary and mesenteric lymph glands from each animal. While there were, occasionally, very noticeable signs of hyperplasia in the lymph nodes and collections of normoblasts in some germ centers which were at least very suggestive of moderately active hemopoiesis. I did not observe extensive manufacture of blood cells, at least the action could not be compared with the extremely marked changes consistently observed in the marrow. The parallelism of changes in the marrow and in the blood stream is so exact that an intimate causal relationship seems certain. The objection may be made that there is no real increase of blood cells, but only a decreased destruction. Such an interpretation is not supported, however, by observations after removal of the normal spleen. All the evidence points rather to an increased destruction of red cells. Splenectomy for hemolytic jaundice, however, is a striking example of a decreased destruction of cells after removal of a presumably diseased spleen.

While I am convinced that this hypothesis is correct, that is, that increased vascularity, increased marrow cell density, and particularly the presence of numerous groups of normoblasts, megaloblasts, and metamyelocytes are evidences of increased marrow function, I must admit that such marrow changes might be explained, theoretically, on the basis of a heightened threshold of cell output, a delayed release of

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7 Hektoen, Ludvig. On the Formation and Fate of Antibodies, Harvey Lectures, Philadelphia, J. B. Lippincott Company, 1910, pp. 150-191.

cells from the marrow into the blood stream, by a retarding of the rate of marrow cell development, or both these factors combined to produce an accumulation of cells in the marrow, as suggested by Ashby<sup>8</sup>

My investigations have been limited to a study of marrow changes which follow removal of the spleen of healthy and apparently perfectly normal animals. What occurs in the marrow after removal of a diseased spleen or the spleen of animals affected by such diseases as pernicious anemia, Banti's disease, kala-azar and leukemia, may be fundamentally different. If, for example, in pernicious anemia, splenectomy is followed by a long continued hyperplasia and erythrocytic hyperactivity, such as is known to follow removal of the spleen of a normal animal, we may have the explanation why some patients with pernicious anemia have shown a definite and quite lasting improvement after splenectomy, as reported recently by Giffin and Szlapka,<sup>9</sup> and by Giffin.<sup>10</sup>

The question of the influence of ether on the marrow is puzzling. I planned to study this problem in a series of four animals, two splenectomized and two nonsplenectomized, using cocain anesthesia during splenectomy and resections of the rib. Ether does not appear to be a significant factor with regard to erythropoiesis. The splenectomized animals show the same increase in erythropoiesis when ether was used as when cocain was used. The nonsplenectomized animals, equally subjected to ether and cocain, failed to show a considerable increase of erythropoiesis. Thus, splenectomy, or its resultant anemia, is clearly the precursor, and apparent cause, of increased erythropoiesis. In the study of the relation of the anesthetic to leukopoiesis, however, individual variations are so marked and the leukogenic reaction so inconstant that it seems doubtful whether a series of four animals operated on under cocain anesthesia is large enough to cover individual variations. My data suggest that ether is a very important factor in the stimulation of leukopoiesis. But the fact that none of the control animals showed a marked change in leukogenic activity, although they were subjected to the same degree and length of ether anesthesia as the splenectomized animals, is evidence that brief ether anesthesia alone is insufficient to affect the leukogenic function of the marrow. Mann<sup>11</sup> has observed that leukocytosis usually follows prolonged ether

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8 Ashby, Winifred. Study of Transfused Blood. II. Blood Destruction in Pernicious Anemia, *J. Exper. Med.* **34** 147-166 (Aug.) 1921.

9 Giffin, H. Z., and Szlapka, T. L. The Treatment of Pernicious Anemia by Splenectomy, *J. A. M. A.* **76** 290-295 (Jan. 29) 1921.

10 Giffin, H. Z. Present Status of Splenectomy as a Therapeutic Measure, *Minnesota Med.* **4** 132-138 (March) 1921.

11 Mann, F. C. Some Bodily Changes During Anesthesia, *J. A. M. A.* **67** 172-175 (July 15) 1916.



anesthesia, that is, after three or four hours, without the removal of any organ. His study, however, was limited to the blood changes. The concurrent marrow function can only be inferred from the changes seen in the blood stream.

It should be borne in mind that in my series of experiments observations of the marrow were not made earlier than two weeks after anesthesia and splenectomy. It is possible that the time of observation was too far removed from the time of stimulus to note the reaction. Further investigation is necessary to arrive at definite and clear cut conclusions regarding the effect of an anesthetic on leukogenesis. It is certain that the erythrogenic reaction observed in the marrow is independent of the anesthetic.

It has been suggested that the marrow reaction which follows splenectomy may be really secondary to the anemia which is known to follow removal of the normal spleen. It is possible that severe hemorrhage or repeated small hemorrhages may cause the same marrow changes as removal of the spleen. Drinker, Drinker and Kreutzman,<sup>12</sup> in their study of the influence of hemorrhage and infusion, noted in their posthemorrhagic cases a hyperplasia of the marrow with extension into the shafts of the long bones of erythrocyte-bearing tissue and many islands showing erythrogenic activity.

Thus hyperplasia and hyperactivity of the marrow after splenectomy are probably physiologic responses to a demand for more blood cells and may have no direct relation to the absence of the spleen. Moreover, the long persistence of this marrow reaction, a persistence of hyperfunction which far exceeds the duration of postsplenectomy anemia, may be likewise an expression of the law of regeneration in excess.

#### SUMMARY

My conclusions regarding marrow changes after removal of the spleen are based on a series of experimental studies of twenty dogs, forty rabbits, and two goats during a period of approximately two years.

The new method of marrow study which I devised for this series of experiments consists of five essential features: (1) a rib marrow specimen removed before splenectomy is used as a control for a series of subsequent specimens removed at intervals after splenectomy. (2) Series of similar rib marrow specimens from normal nonsplenectomized dogs furnish an additional control for the experiments. (3) Rib

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12 Drinker, C. K., Drinker, Katherine, and Kreutzman, H. A. Influence of Procedures Designed to Increase the Rate of Blood Flow Through the Blood-Forming Organs—Hemorrhage and Infusion, *J. Exper. Med.* **27** 383-397 (March) 1918.

marrow specimens removed at frequent intervals after splenectomy give a connected picture of marrow changes (4) The observations on the marrow are correlated with parallel observations on the blood and on the general condition of the animal (5) Ether anesthesia and cocain anesthesia are used in separate series of experiments in order to test the influence of the anesthetic on the marrow

Removal of the spleen of a normal animal is followed by definite hyperplasia and hypertrophy of the marrow The most constant and the most important change in the marrow is an increased production of red blood cells which is clearly observable, on the average, within four weeks after splenectomy and which gradually increases to the maximum about the end of the twelfth week This maximum degree of activity persists for about twelve weeks and then gradually subsides Increased production of the white blood cells is sometimes spectacular, it occurs almost immediately after splenectomy, but it is not only inconstant but also temporary (Fig 12)

The reaction of erythropoiesis in the bone marrow clearly is independent of any of the anesthetics used The series of experiments was too small for conclusive findings with regard to the effect of the anesthetics on leukogenesis

The marrow reaction which follows splenectomy probably is secondary and compensatory to the anemia which follows removal of the normal spleen, thus representing a physiologic response to a demand for more blood cells It may have no direct relation to the absence of the spleen The persistence of this marrow reaction, which far exceeds the duration of postsplenectomy anemia, may likewise be an expression of the law of regeneration in excess

#### PROTOCOL \*

Dog 32, a mongrel terrier, in good condition, weighed 9.2 kg July 11 1919, the erythrocytes numbered 8,000,000, the leukocytes 13,050, and the hemoglobin was 80 per cent

July 14, under aseptic conditions the spleen and a piece of the rib on the right side were removed The specimens were preserved in Zenker's solution The spleen weighed 22 gm Examination of the first specimen of rib marrow showed large islands of marrow cells and many erythrocytes A few normoblasts indicated sluggish erythropoiesis Leukogenesis was more active There was a small central cavity well filled with marrow cells The bone cortex was thick and honeycombed with small islands of marrow cells The vascularity was graded, 1, activity, 1, erythropoiesis, 1, leukogenesis, 1, and density 2

July 28, the erythrocytes numbered 3,736,000, the leukocytes 31,900, and the hemoglobin was 65 per cent

August 1, a second specimen was removed under ether anesthesia The operation lasted twelve minutes Examination of the specimen showed numer-

ous normoblasts suggesting some erythrocytic activity, but leukogenesis greatly predominated. The marrow was definitely more active than that of the first specimen, the control specimen, its leukogenesis was very high. The vascularity was graded 2, activity 3 to 4, erythrocytic 1, leukogenesis 3 to 4, and density 2.

August 12, the dog appeared to be in good condition although thin. The blood was thin, but the wounds had healed without infection. The erythrocytes numbered 3,296,000, the leukocytes 14,700, and the hemoglobin was 35 per cent.

August 13, a third specimen was removed from the left side, midway between the spine and sternum. The pleura was not injured. Examination showed large islands of active marrow cells. Leukogenesis definitely predominated over erythrocytic. The bone cortex was still thick but the cavity was almost solidly packed with marrow cells. The vascularity was graded 2, activity 2 to 3, erythrocytic 1 to 2, and density 2 to 3. In general, the third specimen was about the same as the second.

September 9, the wounds were clean, the animal was very thin weighing only 55 kg. The erythrocytes numbered 4,290,000, the leukocytes 20,000, and the hemoglobin was 40 per cent.

September 10, a fourth specimen was removed without injury to the pleura. The operation lasted twelve minutes, under brief ether anesthesia. Examination of the specimen showed large islands of marrow cells with active hemopoiesis. Leukogenesis still predominated over erythrocytic, however, the latter had definitely increased over that in the second and third specimens. The specimen showed a marked contrast to the first specimen, the marrow core was almost a solid mass of active marrow cells, the bone septums were few and thin, and the marrow islands were all confluent into a solid core. The vascularity was graded 3, activity 3, erythrocytic 2, leukogenesis 2 to 3, and density 2 to 3. The definite increase in erythrocytic was now equal to the leukogenesis.

October 4, a review examination of the four specimens was made with a special bifocal microscope. The notes and drawings are omitted because the findings essentially corroborated those of former examinations.

November 4, the dog weighed 78 kg, its condition was good. The erythrocytes numbered 5,070,000, the leukocytes 15,800, and the hemoglobin was 50 per cent. November 5, the fifth specimen was removed. Examination showed an active, dense mass of marrow cells. The vascularity was graded 3, activity 3, erythrocytic 3 to 4, and density 3. Three other slides of the same specimen gave the same formula.

Jan 28, 1920, the dog weighed 83 kg, it was thin and listless, but the wounds had healed without infection. The erythrocytes numbered 3,610,000, the leukocytes 24,300, and the hemoglobin was 50 per cent. The sixth specimen was removed from a point midway between the spine and sternum. Examination showed the marrow less active than that of the fifth specimen. There was slight fibrosis. The vascularity was graded 3, activity 2 to 3, erythrocytic 2 to 3, leukogenesis 2, and density 2 to 3.

April 21, the dog weighed 99 kg, its condition was good. The erythrocytes numbered 3,800,000, the leukocytes 28,000, and the hemoglobin was 58 per cent. April 22, the seventh specimen was removed. Examination showed large marrow cell islands, active and dense. The bone cortex was still quite

thick, but it had been much honeycombed by small islands of marrow cells. The vascularity was graded 3, activity 3, erythrogenesis 3, leukogenesis 3, and density 3.

July 13, the dog weighed 94 kg, its condition was good although it was anemic. The erythrocytes numbered 4,790,000, the leukocytes 13,950, and the hemoglobin was 68 per cent. July 15, the animal was etherized and an immediate necropsy performed. Specimens of rib marrow from numerous places, all midway between the spine and the sternum, specimens of marrow from the central part of the femur, the hemolymph nodes, the mesenteric and axillary lymph nodes, and the liver were all sent to the laboratory in Zenker's solution. The hemolymph nodes seemed to be slightly hypertrophied, the largest was 4 mm in diameter. The thorax was free from adhesions and signs of infection, the pleura was smooth and shiny everywhere in spite of the numerous rib resections. The animal seemed to have recovered entirely from the severe anemia. The vascularity of the eighth specimen was graded 2, activity 3, erythrogenesis 2 to 3, leukogenesis 2 to 3, and density 2.

primarily to nerve injury. Still others comment on the more or less constant association of primary muscle injury and nerve lesions in these cases.

The pathologic condition found in the muscles of patients with Volkmann's ischemic paralysis has been described by Leser and Powers.

Powers described the muscles as they appeared in a patient operated upon sixteen months after the onset of the disease. The muscles were pale red and very tough and fibrous. Microscopic examination revealed a great hyperplasia of connective tissue around and between the bundles of muscle fibers. The connective tissue was dense and consisted chiefly of adult connective tissue fibers containing a moderate number of blood vessels, most of which had well developed walls. This fibrosis was so complete that in many areas no muscle tissue was present. Muscle tissue appeared atrophic and fragmented. Many fibers had lost their nuclei and transverse striations, having the appearance of broad ribbons of delicate fibrillar tissue. Other fibers had a glassy homogeneous appearance, with a marked affinity for acid stains. Their appearance and reaction strongly suggested hyaline degeneration. Osmic acid preparations showed a moderate amount of fatty infiltration of the connective tissue. No fatty degeneration of muscle fibers was found.

Leser described the appearance of muscle tissue removed from a patient suffering with a Volkmann's contracture of six weeks' duration or longer. In gross the muscle was much paler than normal. On microscopic examination the muscle fibers showed evidences of degeneration manifested by breaking up of the fibers into Bowman's disks, loss of muscle nuclei and marked decrease in the size of the muscle fibers. There was no fatty degeneration of the muscle. There were evidences of an acute inflammatory reaction manifested by a marked leukocytic infiltration. There was also a marked growth of very cellular connective tissue, which in many areas had completely replaced muscle tissue. The author describes in detail the endothelium of small vessels. It was not flat but thick. This he interprets as being due to the fact that endothelial cells are elastic, and, hence, when the blood pressure in small vessels was decreased, the endothelium became much thicker. He states that the changes seen in the muscle indicated two processes at work: (1) degeneration of the muscle tissue, (2) a marked inflammatory process in the muscle.

In addition to the paralysis and contractures which follow the application of constricting bandages, paralysis following ligation of large arteries for wounds has been described by Sherril,<sup>9</sup> Hirschmann.<sup>10</sup>

9 Sherril. *Old Dominion J* **18** 113, 1914.

10 Hirschmann. *Zentralbl f Chir* **44** 239, 1917.

Verdeht,<sup>11</sup> Burrows<sup>12</sup> and Leriche<sup>13</sup> Leriche believed that the paralyses were not due so much to the actual damage to the artery as to the accompanying vasomotor nerves Desplats and Buquet thought the paralyses were due to temporary or permanent ischemia of the terminals of the nerves Burrows thought the paralyses and anesthetics following the ligation of large arteries were both of ischemic and reflex nature In the former there was complete cessation of the pulse in the large arteries, subjective sensations of pins and needles, stocking and glove anesthesia and muscular paralysis with the muscles hard and inelastic In the reflex paralysis the pulse in the larger arteries was not completely lost There were no subjective sensations There was widespread anesthesia and muscular paralyses in which the muscles were soft and flaccid

In a single case in which extensive paralysis followed ligation of the popliteal artery, the gross and microscopic appearance of the paralyzed muscles, from eleven to fourteen days after the injury, was described The muscle gave the appearance of an anemic infarct The muscle fibers and interstitial tissue stained a uniform pink with eosin The muscles showed extensive degeneration Some preserved their striae but no nuclei Others appeared as granular masses Some were broken transversely into disks and others split longitudinally into fibrillae The interstitial tissue was edematous and almost no nuclei were seen *There was but a slight trace of inflammatory reaction*

Tinel<sup>14</sup> writes concerning ischemic paralysis thus

In the first phase of ischemic paralysis of the upper extremity the affected limb is edematous, cyanosed and cool After a period of two or three months, there is fibrous transformation of this edema This progressive sclerosis makes the subcutaneous cellular tissue puffy, invades the dermis, contracts the muscles, hardens the aponeuroses submerges the tendons and synovial sheaths into a veritable fibrous mass gives the tissue a woody consistence, and finally transforms the hand into a fibrous bat With this characteristic appearance are associated certain signs There is a complete absence or marked diminution in the radial pulse with a much lower blood pressure than on the nonaffected side There is almost always pain, accompanied by subjective sensation, as burning, tingling or formication Deep pressure or contact with heat or cold is often very painful Some cases of ischemic paralysis are almost free from pain In contrast with this painful sensibility which appears to be deep seated, there is usually considerable anesthesia affecting all the superficial sensations The anesthesia predominates at the extremity of the limb and decreases toward its origin The electrical reactions of the muscles are profoundly disturbed We find the typical reaction of degeneration, particularly hyperexcitability, sometimes with abolition of all electrical excitability This is rather the syndrome of fibrous

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11 Verdeht J de med d Bordeaux **87** 50, 1916

12 Burrows, H Brit M J **1** 199 (Feb 16) 1918

13 Leriche Rev d med **30** 578, 1916

14 Tinel, J Nerve Wounds, New York William Wood & Co, 1917

transformation of the muscles. The muscles may react only to a very intense current. There is no polar inversion and often stimulation of the nerve at a distance provokes movements more readily than does excitation of the muscle.

It would seem, therefore, from these clinical observations that there was such a thing as a paralysis of muscles following an obstruction of the blood supply to these muscles, and that the paralysis might be independent of injury to nerve trunks. The evidence, however, for such a conclusion is not complete since the possibility of injury to nerve trunks has always to be considered in instances in which wounds of vessels have occurred or instances in which constricting bandages are applied to an extremity. It is worth while noting here that actual paralysis of muscles is not noted in a collection of ligations of great vessels, such as, for example, in that of Halsted's collection of instances of ligation of the common iliac artery, although gangrene of the extremity was noted in a considerable number of instances. Furthermore, paralysis of muscles does not accompany progressive obliteration of arteries in arteriosclerosis even when the occlusion is so extensive as to cause gangrene.

There are two distinct phases of ischemia which have not been differentiated. The arterial blood supply to an extremity may be markedly decreased over an indefinite period or the extremity may be completely deprived of blood for a limited period only. The susceptibility of the various tissues concerned to these different types of ischemia has not been studied.

The results of the obstruction of the veins alone or the arteries alone of an isolated muscle have not been studied.

#### EXPERIMENTS WITH TOURNIQUETS, SPLINTS, AND PLASTER BANDAGES

Three experiments in which constricting bandages were applied to the extremity were carried out. In one instance a tight muslin bandage was applied above the elbow of a dog and left in place for twenty-four hours. The animal was given frequent doses of morphin in order to prevent as much as possible the severe pain which would seem almost certainly to accompany such a procedure. At the end of this time, the extremity distal to the bandage was very much swollen and cold. The bandage was removed. The swelling promptly disappeared and no paralysis was observed. In another experiment a very tight Esmarch rubber bandage was applied above the elbow of a dog and left in position for a period of five hours. When it was removed there was complete paralysis of the muscles of the extremity distal to the bandage, and, apparently, a marked impairment of sensation. The animal was allowed to live for a period of three weeks, during which time the paralysis remained complete. The muscles, however, remained soft and flaccid, and microscopic examination revealed nothing more than

the decrease in size of the fibers and the loss of definition of the striation which is seen after nerve section. In another experiment a tight rubber bandage was applied above a dog's elbow and left in place for five hours. A complete paralysis of the fore leg resulted. The animal was anesthetized on the following day and the nerves and muscles exposed. It was found that stimulation of the nerve trunks above the level of the tourniquet caused no muscle contractions, while stimulation of the same nerves below the level of the tourniquet caused prompt contraction of the muscles.

From these and a few other preliminary experiments, it seemed that with any method of constriction of the entire extremity it was difficult to separate the effect of direct pressure on the nerves and the circulatory disturbance of the various tissues as causes of any paralysis obtained. Furthermore, the degree and character of circulatory disturbance could not be controlled.

#### EXPERIMENTS IN WHICH THERE WAS PERMANENT OBSTRUCTION OF THE PRIMARY ARTERIES OF AN EXTREMITY

The circulation in the dog is of such a nature that ligation of any single, large, peripheral artery produces no disturbance in circulation of sufficient degree to alter the function of an extremity. A marked disturbance in the function of the posterior extremities, however, does follow ligation of the abdominal aorta between the origins of the inferior mesenteric and iliac arteries. The function of one posterior extremity may be altered by unilateral multiple ligations of the terminal branches of the aorta. That this disturbance in function is not due to any disturbance in circulation in the spinal cord is clearly shown by the fact that none of the arteries ligated send any branches to this structure, and, furthermore, the artery may be obstructed for several hours and on removal of the obstruction there may be a complete recovery from the paralysis. This is in contradiction to the known fact that the brain and cord will not recover function after much shorter periods of anemia.

#### REPORT OF EXPERIMENTS

EXPERIMENT 101—Dog 41, a large female, was operated on under ether anesthesia, May 19, 1921. The abdomen was opened, the aorta was ligated proximal to the origin of the iliac arteries and the abdomen was closed. Five hours after operation, the animal was standing in the cage. Both thighs were warm. The legs and feet were "cool" but not "cold." Twenty-four hours after operation the animal was taken from the cage. It walked with the hind legs held rather stiffly, but it started walking with very little difficulty. After walking about 100 feet (30.5 meters) the hind legs began to "give way", and after a few minutes of effort to walk the hind legs became apparently completely useless. The



animal was allowed to rest for three hours, after which the experience described above was repeated. At this time the disability appeared after somewhat more exertion.

After three days the animal was apparently quite normal and did not show any evidence of weakness in the hind legs after fifteen minutes walking. Four

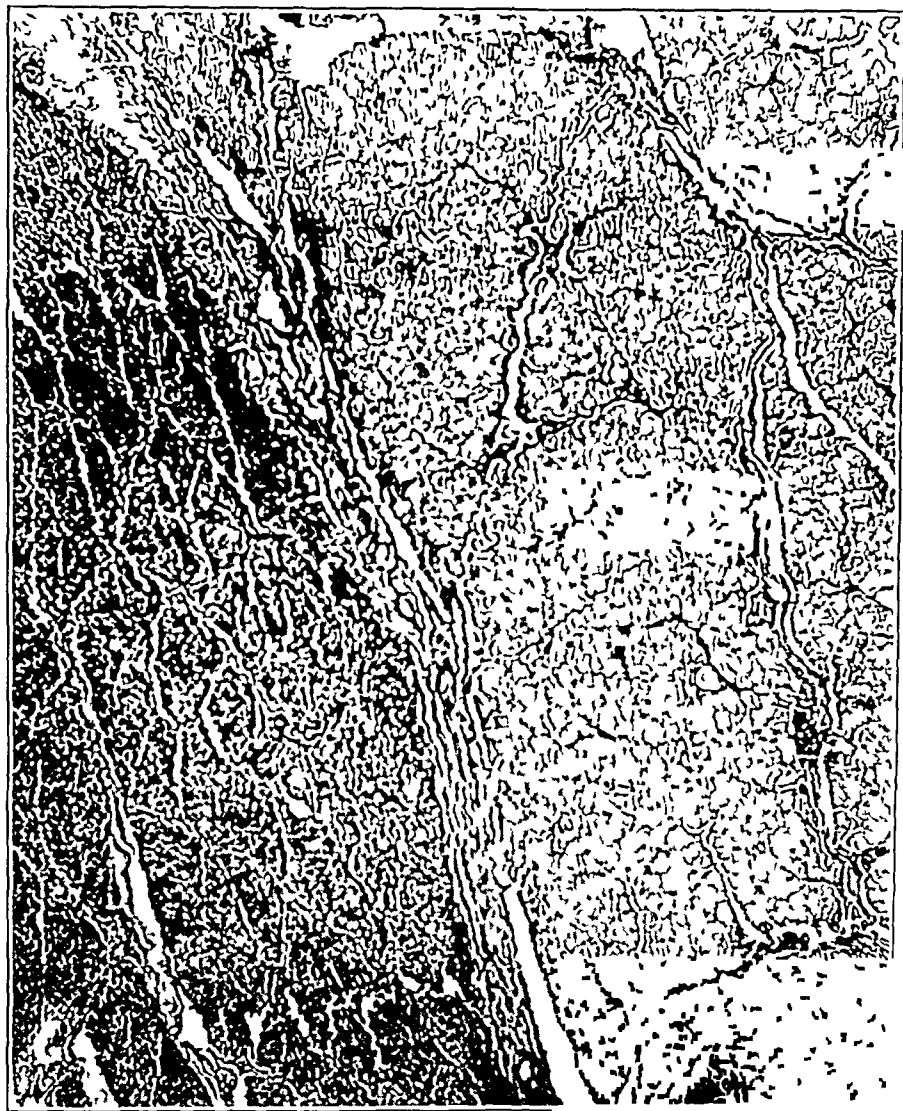


Fig 1—Photomicrograph of a cross section of the tibialis anticus muscle fourteen days after ligation of the primary arteries of the extremity, showing an area of degeneration of the muscle. The area of degeneration is sharply circumscribed. There is no evidence of acute inflammatory reaction in the area of degeneration or in the surrounding nondegenerated muscle. See description of Experiment 37.

months after operation, the animal was apparently perfectly normal. It was killed. The left femoral artery was divided in the mid thigh and the proximal stump injected with a thin paste made of freshly precipitated barium sulphate. A roentgenogram of the entire animal showed a complete injection of all the

arteries of the body. The paths of communication between the proximal and distal stumps of the ligated aorta was through the anastomoses of the mammary and the deep epigastric arteries. These anastomotic arteries lay in the rectus abdominis muscles. The communicating branches were surprisingly few in number and small in size. It was most remarkable to find that such a small arterial communication between the heart and the arteries of the pelvis could

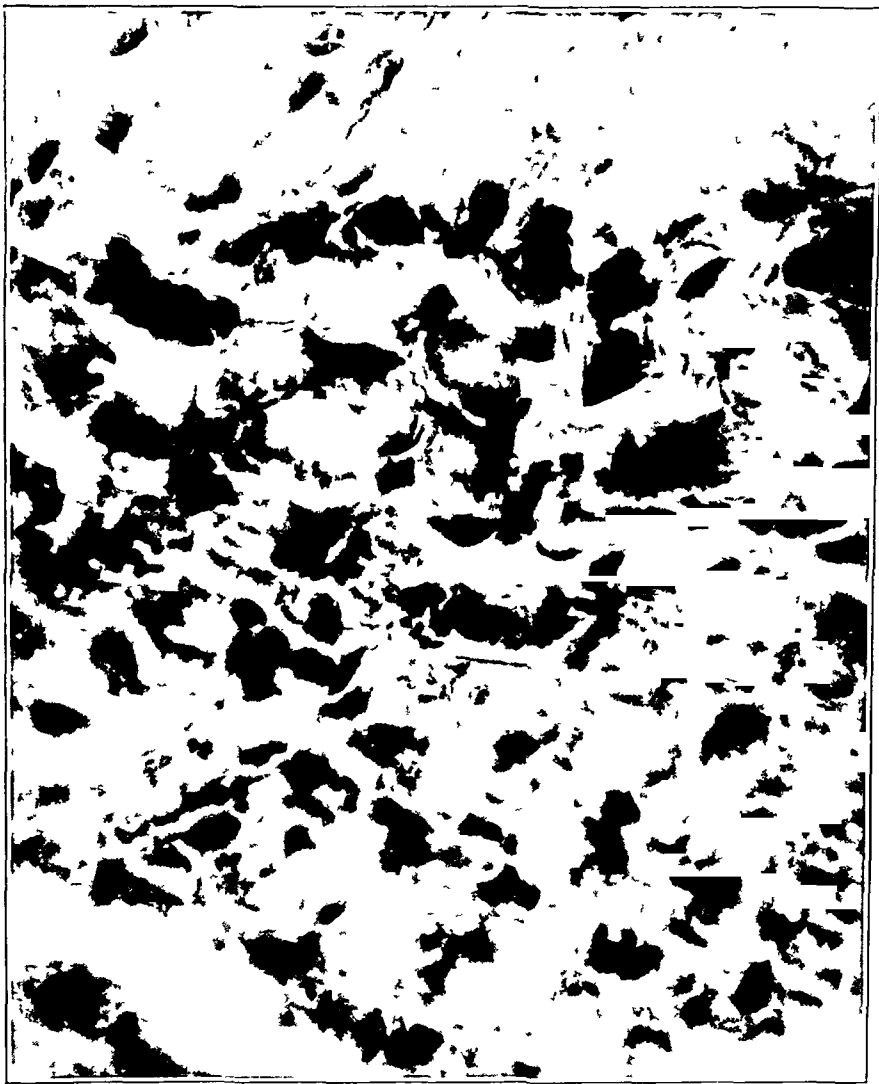


Fig. 2—High power magnification of the degenerated area shown in Figure 1. The absence of leukocytic infiltration or fibrous tissue formation may be noted.

preserve the apparently perfect anatomic and functional integrity of the entire posterior half of the body.

EXPERIMENT 37—Dog 73, was operated on, March 4, 1921, under ether anesthesia. The abdomen was opened and the aorta ligated distal to the origin of the iliac arteries, the left iliac artery was ligated and the abdomen was closed. An incision was made in the middle of the left thigh and the femoral artery was ligated. The wound was closed.

Three hours after operation the animal walked on the leg. The leg felt cold, the muscles of the leg felt tense, and the animal walked as if he had a peg leg. There was no evidence of pain, no swelling and no edema. Six hours after operation the condition was the same. The muscles of the leg were tense. No voluntary movement could be detected. The animal flinched from a pin prick.



Fig 3—Photomicrograph of a cross section of an "isolated muscle" twenty-four hours after ligation of its vein, showing extravasation of blood into the muscle and nerves, the vein is occluded by a thrombus, the artery is not thrombosed.

anywhere in the leg. When the animal attempted to step on the foot the toes turned backward. Twenty-four hours after operation the muscles of the leg were tense. Apparently there was weakness but not complete paralysis. There was no swelling and no contracture. Two days after operation the animal did not use the leg for walking. The muscles were held tense. There was no swelling below the knee. The thigh was slightly swollen and apparently the

muscles were tender. Four days after operation the animal walked on the leg, with a limp. The entire extremity was swollen. There was an area of beginning gangrene of the skin on the medial surface of the leg and thigh. Fourteen days after operation, well defined, dry gangrene of the skin of the foot, leg, and distal third of the thigh was observed. The line of demarcation of the gangrene was sharp. It encircled the thigh at the junction of the middle and distal

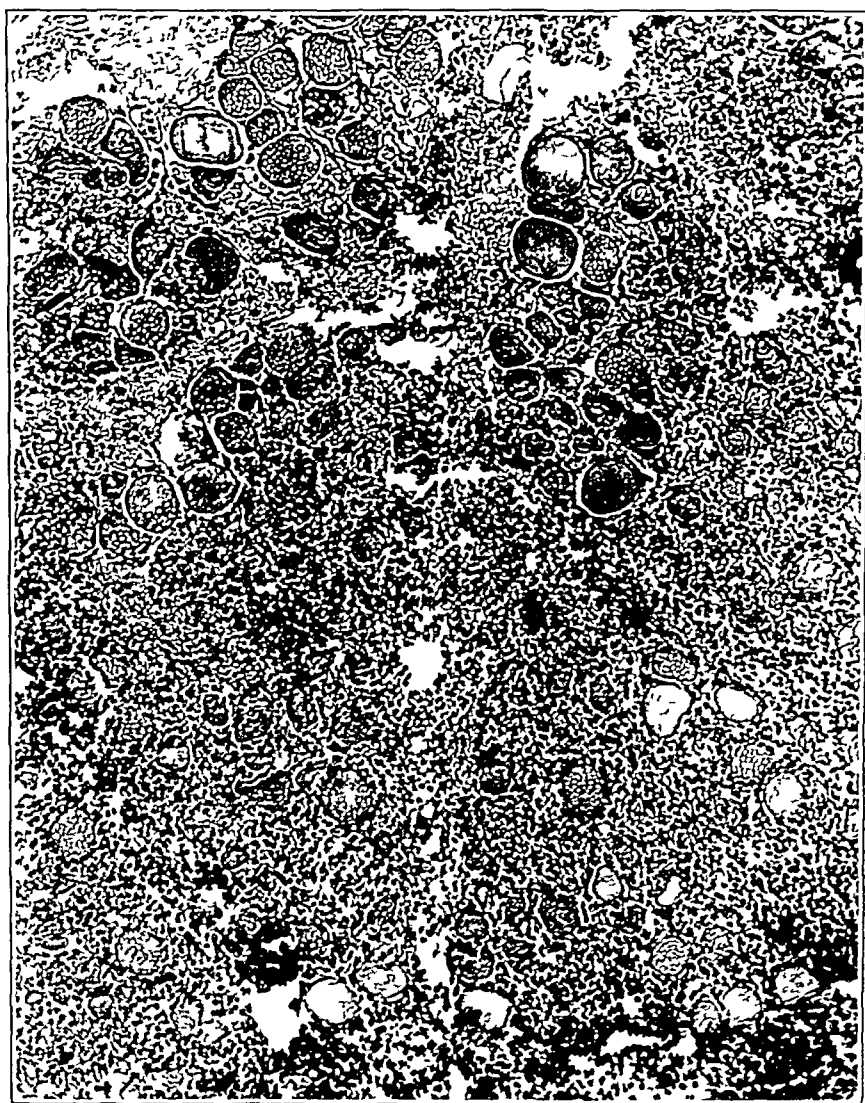


Fig 4—Photomicrograph of a cross section of a muscle two days after ligation of its vein, showing extensive infiltration of the muscle by polymorphonuclear leukocytes, the muscle fibers are swollen and vacuolated

thirds. The animal was anesthetized and the gangrenous skin was removed. The muscles of the thigh and leg appeared normal. The tendons of the leg muscles were gangrenous in the foot. All the muscles contracted on stimulation of the muscles or nerves. On section all of the muscles appeared normal except the anterior tibial muscle. This muscle appeared normal externally, but on

section there was, in the substance of the muscle a pale firm area, cylindric in shape, measuring 0.5 cm. in diameter and extending the entire length of the muscle. This area had the appearance of an infarct.

Microscopic examination of the muscles showed no abnormality except in the anterior tibial muscle. Microscopic examination of this muscle in cross

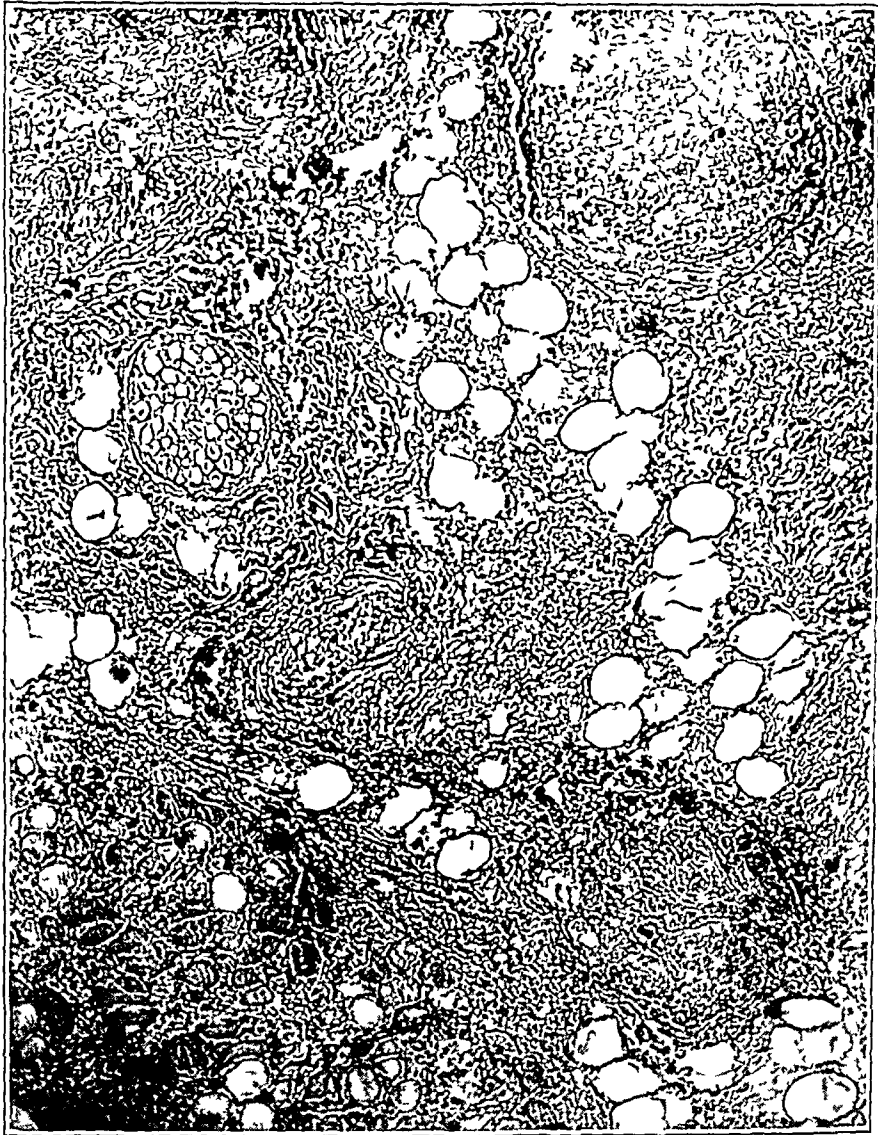


Fig 5—Photomicrograph of a cross section of a muscle four days after ligation of its vein, showing infiltration with polymorphonuclear leukocytes and a beginning fibrous tissue reaction.

section showed the periphery of the muscle approximately normal. The central pale area showed a marked change in the muscle tissue. The muscle fibers were much shrunken and closely packed together. The nuclei of the muscles stained well. There was no massive necrosis. There was very little reaction in the muscle stroma. The area of degeneration was sharply defined from normal appearing muscle. There was very little reaction at the periphery of the area of

degeneration Microscopically, the area proved to be one of a sharply localized muscle degeneration rather than actual massive necrosis Reaction within or about the area of degeneration was strikingly absent A photomicrograph of this area and the surrounding muscle tissue is shown in Figure 1

EXPERIMENT 29—Dog 141 was operated on, Feb 11, 1921, under ether anesthesia The abdomen was opened all branches of the aorta distal to the origin



Fig 6—Photomicrograph of a muscle four days after ligation of its vein, showing the infiltration of the muscle by polymorphonuclear leukocytes

of the inferior mesenteric artery, with the exception of the right iliac artery, were ligated, the left deep epigastric was ligated near its origin from the iliac artery, and the abdomen was closed A small incision was made in the left mid thigh and the femoral artery was ligated

February 12, twenty-four hours later, the left thigh was slightly edematous, the leg was cold Apparently there was complete paralysis of the entire left

posterior extremity Through the skin, all muscles felt normal The muscles of the leg contracted to strong faradic stimulation Contractions were less powerful than in the right leg

February 13, after forty-eight hours, the animal did not eat, it looked sick The left thigh was tremendously swollen There was no swelling below the knee The entire extremity was apparently useless There was very slight



Fig 7—Photomicrograph of a cross section of a muscle ten days after ligation of its vein, showing fibrous transformation of the muscle

movement in the muscles at the hip and no motion below the knee The skin of the thigh showed marked bluish discoloration There was a fairly sharp line of demarcation around the proximal thigh, between the discolored and normal skin

The animal was anesthetized and the muscles of the extremity were examined before the animal was killed Below the knee the muscles looked strikingly normal in color and form They were not swollen There was no visible

edema. The muscles did not react to electrical nor mechanical stimulation. Stimulation of the nerve trunks caused no contraction in the muscles below the knee. Stimulation of the sciatic nerve in the mid thigh gave no effect on respiration.

The muscles of the thigh were tremendously swollen and very pale. There was a large amount of fluid in the muscle and in the intermuscular spaces. The

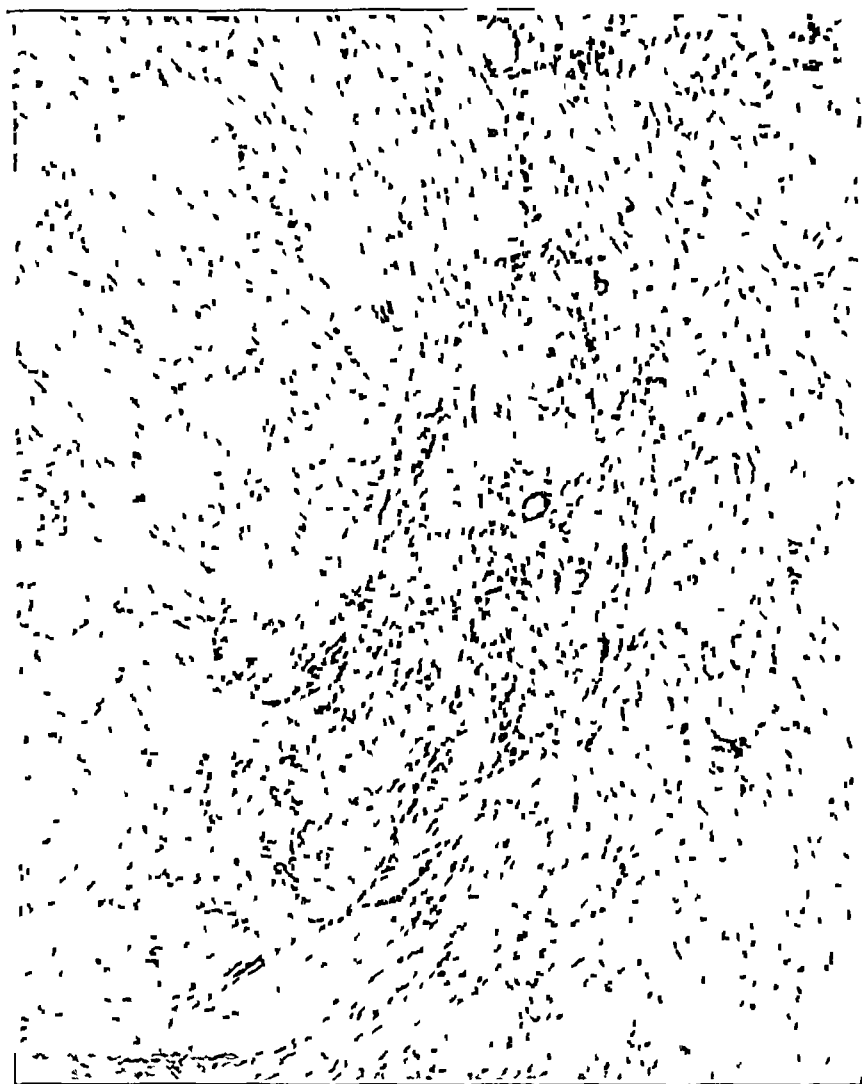


Fig 8—Photomicrograph of a cross section of a muscle thirty-one days after ligation of its vein, showing complete fibrous transformation of the muscle

muscles did not contract to mechanical or electrical stimulation. The muscles became red on exposure to the air.

The gluteus maximus muscle was brick red in color, it bled slightly on section. It contracted promptly on stimulation by a strong faradic current. The contractions were weak and the muscle fatigued quickly.

All muscles were either totally paralyzed and necrotic or totally not paralyzed and viable, except the rectus femoris muscle. This muscle showed



both conditions in the same muscle. The distal half was clearly necrotic and completely paralyzed, the proximal half was clearly viable and contracted promptly on electrical stimulation. The line of demarcation between the viable and nonviable muscle was sharply defined, and coincided with an equally sharp line of definition between the irritable and nonirritable muscle.

In Experiments 101, 37 and 29 just described, there were changes in physiologic and anatomic integrity of the muscles as a result of the obstruction of the arterial supply to the extremity.

In Experiment 101, in which the ligation of the aorta produced a marked diminution in the blood supply to the posterior extremities, there was a temporary change in the physiology of the muscles of the extremity but no demonstrable anatomic change. Immediately following the obstruction to the arterial supply the muscles of the extremities, although at no time completely paralyzed, were constantly in a state of exaggerated tension, and the extremity after even a few minutes of exercise became useless. This condition was relieved by rest and appeared again after repeated exercise. Three days after the arterial obstruction, the animal did not lose the use of the extremities after a considerably longer period of exercise, and at the end of four months, it showed nothing abnormal in function or structure of the muscles, although it was possible to establish only a very small arterial connection between the heart and the posterior extremities.

In other experiments it has been found that the loss of function of the posterior extremities after ligation of the aorta has been complete for two or three days and the period of complete recovery extended to several days, but in all instances in which the animal has not died or developed gangrene, the recovery has been complete and the muscles have shown no pathologic change.

The condition developed in this experiment corresponds to the condition, well known in clinical medicine, to which the term ischemia has been applied. It has been noted in man after occlusion of such large arteries as the common iliac or axillary. It is almost certainly a fatigue phenomenon. With the marked decrease in arterial blood supply, the muscle becomes rapidly profoundly fatigued.

In Experiment 29, in which the arterial blood supply to one extremity was markedly reduced by ligation of several arteries, gangrene of the extremity resulted. It is important to note that all tissues of the extremity were included in the necrosis. The muscles of the most distal portion of the extremity were apparently completely deprived of all fluid. They became necrotic en masse, without hemorrhage, edema, or any evidence of inflammatory reaction. Some of the muscles of the thigh were apparently deprived of blood but did absorb fluids from lymph vessels or neighboring viable tissues. Some of the muscles received enough circulation to preserve their normal physiologic reactions. It is

interesting that the borderline muscles either became completely necrotic or remained wholly viable. The one exception to this was the rectus femoris muscle. The distal half of this muscle became gangrenous and the proximal half remained almost normal in appearance. The junction of the dead and living muscle was sharply defined. Of even more interest, however, is the fact that the part of the muscle

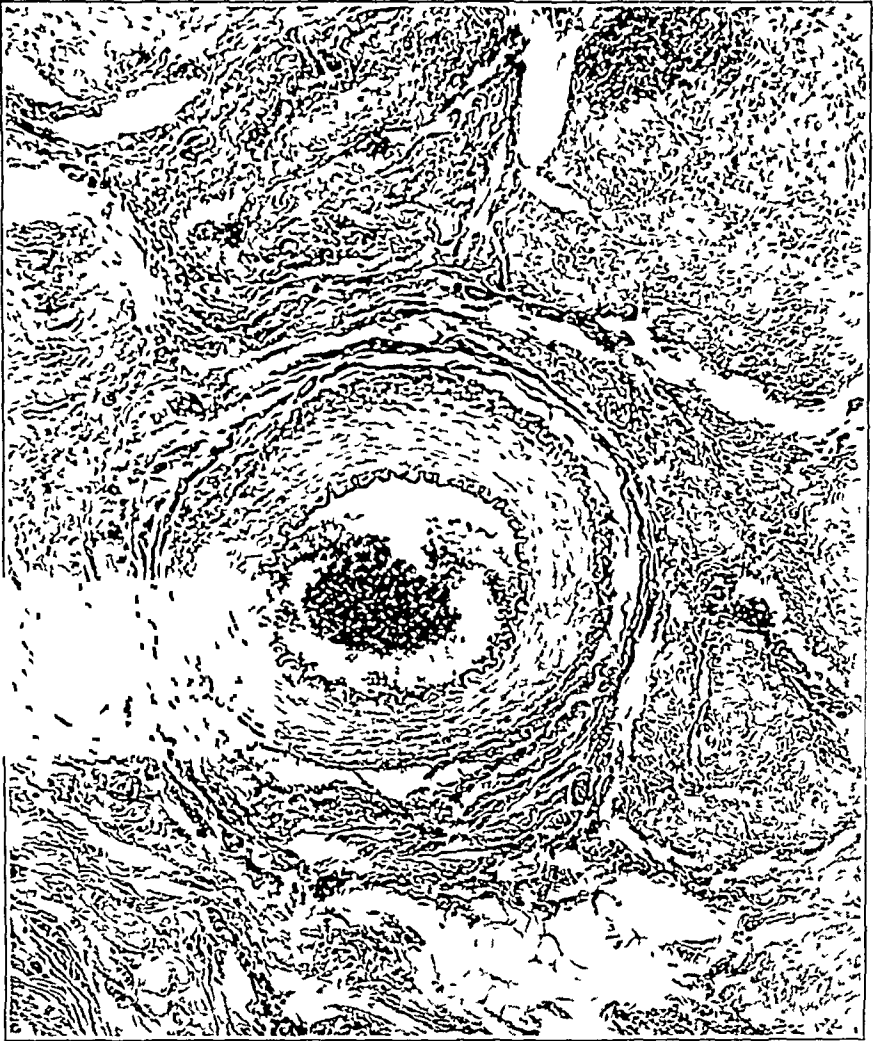


Fig 9—Photomicrograph of another area of the section shown in Figure 8, showing the preservation of the arteries in the muscle

which preserved its anatomic integrity also wholly preserved its physiologic properties (except, no doubt, this part of the muscle would have exhibited the phenomenon of rapidly developing fatigue or "ischemia"). In this long muscle, which gets its arterial supply near its proximal end, we are justified in assuming that following the obstruction to the large arteries the blood supply to this muscle

was most abundant at the proximal end and continuously decreased toward the distal end. Under such conditions, therefore, there was no "zone" in which the blood supply was sufficient to keep the muscle alive but not sufficient to permit it to contract. It is, of course, theoretically possible that the blood supply of a muscle be just sufficient



Fig 10—Photomicrograph of a cross section of a muscle thirty-six days after ligation of its vein, showing the fibrous transformation of the muscle. A few degenerating muscle fibers can be seen.

to take care of an infinitesimal amount of muscle activity so as to keep the muscle in a permanent state of complete fatigue. Practically, this is not possible because the blood supply of a region supplied by an artery is always most profoundly limited immediately after the

obstruction of this artery. The quantity furnished by collateral circulation (if any at all is furnished) always increases for a certain period.

Experiment 37 is of particular interest because it was the only instance in which a process of degeneration rather than massive necrosis of muscle followed permanent occlusion of the arteries to an extremity. In this experiment there was an isolated area of degeneration of muscle fibers in a single muscle, the remainder of this muscle and all the other muscles of the extremity remained normal in appearance and reaction in spite of extensive gangrene of the skin.

In all of the experiments in which the arteries to an extremity were permanently occluded, and in which the diminution in blood supply to this extremity was sufficient to produce pathologic changes in the tissue the skin showed the most extensive change.

#### EXPERIMENTS IN WHICH THERE WAS A TEMPORARY OBSTRUCTION OF THE PRIMARY ARTERIES OF THE EXTREMITY

EXPERIMENT 33—Dog 122 February 20 10 a m under ether anesthesia was operated on the abdomen being opened and the aorta ligated distal to the origin of the iliac arteries. The deep epigastric artery was ligated. A clamp was applied to the left iliac artery. The abdomen was closed. An incision was made in the left thigh. The femoral artery was clamped and the incision closed.

February 20, 4 p m, six hours after operation, the entire leg and distal half of the thigh were cold. The animal stood on the leg. It used the muscles of the thigh, but the muscles of the leg were held stiffly and apparently were useless. Electrical stimulation through the skin caused prompt contractions in the thigh muscles, very weak contractions in the posterior muscles of the leg, and no contractions could be obtained in the anterior leg muscles.

The animal was anesthetized and the clamps were removed from the iliac and femoral arteries. Pulsation immediately returned in the femoral arteries. The skin of the entire leg and of the distal half of the thigh became deeply flushed. There was a fairly sharp line of demarcation between the flushed skin and the paler skin in the midthigh. Ten minutes after removal of the clamps from the arteries all muscles of the leg reacted to electrical stimulation. The contractions in the anterior muscles were not so strong as normal. On the following day there was no visible paralysis. One week later the animal was killed and nothing abnormal could be found in the muscles of the extremity.

EXPERIMENT 34—February 24, 4 00 p m, on Dog 101, the same operative procedure was carried out as in Experiment 33.

February 25, 9 00 a m, seventeen hours after operation, there was complete muscular paralysis below the knee, but no swelling. The leg was not cold. Electrical stimulation of the muscles below the knee caused no contractions.

February 25, 4 00 p m, twenty-four hours after operation, there was complete paralysis below the knee. The leg felt cold. The animal was anesthetized and the clamps were removed from the iliac and femoral arteries. Pulsation immediately returned in the femoral artery. The skin below the knee was flushed to a bright pink. The flush was sharply defined at the level of the knee. Five minutes after removal of the clamps there was no demonstrable electrical irritability of the muscles below the knee.

February 26, complete paralysis existed below the knee. The muscles of the leg were swollen and definitely harder than normal.

February 28, four days after clamping the vessels and three days after removal of the clamps, the muscle paralysis remained unchanged. The entire extremity was swollen. It was definitely warmer than the normal leg. The swelling was apparently entirely in the deeper structures. The skin looked normal, the femoral pulse was good. There was no contraction of the muscles below the knee from electrical stimulation. Pain sense was apparently impaired below the knee but it was not absent. The animal was anesthetized. An incision was made exposing the deeper structures of the leg and thigh. All the larger arteries of the extremity pulsated. There was good pulsation in the arteries of the foot.

The muscles of the leg were swollen, harder than normal, and of a blue hemorrhagic color. On section of the muscle there was active bleeding from the larger arteries in the muscle. There was, however, no capillary bleeding and no demonstrable irritability of any muscle of the leg.

The muscles of the thigh were particularly interesting. The gluteus maximus muscle appeared normal and was irritable. The same was true of the rectus femoris and sartorius muscles. The deeper extensor was swollen, hemorrhagic, and showed no irritability. The distal half of the lateral extensor muscle of the thigh was swollen, hemorrhagic and completely paralyzed, the proximal end appeared normal and contracted normally on electrical stimulation. The junction of the abnormal muscle and normal muscle was sharply defined and coincided absolutely with the junction of the irritable and the paralyzed muscle.

Microscopic examination of the muscles of the leg showed the muscle fibers strikingly normal in outline. In some areas there was a complete absence of staining of nuclei, giving a picture of massive necrosis of all the tissues. In other areas there was hemorrhage between the fibers and an accumulation of a few polymorphonuclear leukocytes. The larger arteries contained blood and showed no evidence of thrombosis. Many arteries and veins, however, were thrombosed. In general the areas of hemorrhage and leukocytic infiltration were near the arteries which were not thrombosed. The paralyzed muscles of the thigh showed much the same picture, except that the areas of hemorrhage and leukocytic infiltration were relatively more extensive, and the areas in which there was massive necrosis without evidence of any reaction were smaller.

A longitudinal section of the junction of the paralyzed and nonparalyzed portions of the lateral extensor of the thigh showed varying grades of muscle necrosis and degeneration limited to a small zone. The more distal portion of the muscle was completely necrotic, with no hemorrhage or leukocytic infiltration. Proximal to this was a zone of hemorrhage and leukocytic infiltration. Normal appearing fibers reached to this zone, but in the immediate proximity of the hemorrhage some of the muscle fibers were very much swollen and fragmented.

EXPERIMENT 36—Dog 61, on March 2, under ether anesthesia, was operated on, the abdomen being opened and the clamps being applied to (1) the aorta distal to the origin of the iliac arteries, (2) the left iliac artery, and (3) the left femoral artery in the midthigh.

Seventeen hours after operation there was apparently complete paralysis below the knee. The knee was extended and the foot was flexed. The leg was held stiffly, the muscles were tense. The foot and leg were cool but not

cold. Stimulation of the muscles of the leg caused no visible contractions. The animal was anesthetized and all clamps were removed. A feeble pulse returned in the femoral artery. The skin below the level of the knee was flushed pink. There was no demonstrable evidence of return of irritability of the muscles of the leg.

March 4, the animal walked on the leg with a limp. "Paralysis" was not complete.

March 9, six days after removal of the clamps from the arteries, there was no contracture of the muscles. The animal did not use the leg for walking, but apparently it was not completely paralyzed. There was a small ulcerating area in the skin. The animal was anesthetized. The skin was dissected away and the muscles were inspected before the death of the animal. The anterior muscles of the leg were very pale and showed no contraction after electrical or mechanical stimulation of the nerves. The posterior muscles of the leg were mottled with areas of pink muscle and pale yellowish muscle. The pink areas contracted on electrical stimulation. The pale areas showed no sign of being irritable. A similar picture was shown by the muscles of the thigh.

The results of these experiments in which there was temporary obstruction of the arteries to an extremity are different from those in which the obstruction was permanent. In the latter the demonstrable pathologic change was always most extensive in the skin, while in the former the most extensive damage was in the muscles. In Experiment 33 in which the arteries were obstructed for six hours, the leg became cold, completely paralyzed, and some of the muscles showed no irritability to electrical stimulation. Following the removal of the obstruction to the arteries, there was an immediate return of function of the muscles and no demonstrable anatomic change in any tissues of the extremity.

In Experiment 34 in which the arteries were obstructed for seventeen hours, and in which the relief of this obstruction was followed by a good pulse in all of the larger arteries of the extremity, there was at the end of four days extensive necrosis of the muscles. This necrosis was accompanied by the presence of a large amount of hemorrhage and edema. The skin was not at this time visibly changed. The muscle necrosis was so extensive that it included all, or most, of the muscles of the extremity. The muscles in general became completely necrotic or remained completely viable, half of one muscle of the thigh was necrotic and the other half was viable and retained its physiologic reactions. This extensive necrosis occurred in spite of a restoration of a pulsating blood stream in all of the larger arteries, even the arterial branches to the muscles bled within the necrotic muscles. The reaction of the tissues of the extremity to the extensive damage following the obstruction to the circulation was interesting. During the period of arterial obstruction there were no manifestations of inflammation. One day after the removal of the obstruction to the arteries there was some

swelling, and at the end of four days the swelling had increased and the extremity was distinctly warmer than the normal extremity. At this time microscopic examination of the muscles showed some infiltration of leukocytes in the vicinity of functioning blood vessels. There was, however, no evidence of a fibrous tissue reaction at this time.

Experiment 36 is interesting from the standpoint that arteries of the extremity were obstructed for the same period as in Experiment 34, but following the removal of the clamps, the circulation was not completely restored to the large arteries. The femoral artery had only a very feeble pulsation. The extent of muscle damage was distinctly less than in Experiment 34, and there was at the end of six days no evidence of hemorrhage and edema of the muscles. Also there was not at any time any swelling or manifestations of marked inflammatory disease. There was, however, ulceration of the skin. This experiment is interesting in its relation to the belief of Rowland that ischemic contractures were the result of the sudden release of obstruction to arteries after a period of anemia, and to the generally accepted treatment of the anemia of the extremity following exposure to cold, in which it has been found that a gradual restoration of circulation or more accurately a gradual restoration of the normal temperature is not so likely to produce disastrous results as the sudden warming of the extremity.

#### EXPERIMENTS ON THE ISOLATED MUSCLE

In order to study more accurately the effect of circulatory disturbance on the muscles, independent of the other tissues of the extremity, a series of experiments on the isolated muscle were carried out. The rectus femoris muscle was chosen on account of its accessibility and the fact that its circulation is supplied by a single artery and vein which are easily isolated. Also the nerve supply is a single branch of the femoral nerve which accompanies the nutrient artery and vein. The experimental method which was the same in all experiments is described below.

The dog was anesthetized and an incision was made on the anterior surface of the thigh and distal third of the abdomen. The rectus femoris muscle was freed from the surrounding tissues everywhere except from tendinous origin from the ilium and insertion into the quadriceps tendon. The artery, nerve, and vein were completely isolated from one another and the fibrous tissue accompanying them was divided. A tight ligature was tied about each end of the muscle. This gave a muscle completely isolated from all vascular connections except a single artery and a single vein. The nerve supply was intact. The circulation in the surrounding tissues was normal. The following series of experiments were carried out on these isolated muscles.

1 *Section of Nerve—Artery and Vein Intact*—In the experiments in which the nerve alone was sectioned, leaving the isolated muscle with its artery and vein intact, the muscle was completely paralyzed. It decreased markedly in size and microscopic examination showed marked diminution in the size of the muscle fibers and loss of definition in striation. Occasionally fibers which showed degeneration were found. There was no evidence at the end of periods of as long as a month of any inflammatory reaction or fibrosis. The process was one primarily of atrophy rather than degeneration.

2 *Injection of Blood into the Muscle*—In two experiments after isolation of the muscle, 10 c.c. of blood was aspirated from the femoral vein and injected into the body of the muscle in several places, so that the muscle was markedly distended with blood. In another experiment the same procedure was carried out and in addition the artery was tied. The animals in which these experiments were carried out were killed at the end of one month. Examination of the muscles showed nothing abnormal in their physiologic reactions, and microscopic examination showed no evidence of inflammation or fibrosis.

3 *Ligature of the Artery Leaving Vein Intact*—In eleven experiments only the artery of the isolated muscle was ligated. In these experiments, therefore, a single muscle was completely separated from all arterial supply. The nerve and vein remained intact. The circulation of the surrounding tissues was not disturbed. The operation wounds were carefully closed so as to obliterate all cavities. The animals were killed at the end of periods of from seven to sixty days and the muscles were examined. In every instance the muscle showed normal physiologic properties. The muscles were always more adherent to the surrounding tissues than normal. In no instance was the muscle fibrous. Microscopic examination of the muscles showed slight degenerative changes in some instances, but in no instance was there found marked inflammatory reaction or fibrous change of the muscle.

In one experiment the artery and nerve were sectioned. Examination of this muscle after a period of sixty days showed the typical atrophy of nerve paralysis.

In five experiments the artery of the isolated muscle was tied and in addition the circulation of the entire extremity was diminished by ligation of branches of the aorta. In one of these experiments the iliac artery was tied after the isolation and ligature of the nutrient artery to the rectus muscle. Examination of the muscle three days later showed the muscle edematous, but the physiologic reaction was normal and microscopic examination showed only slight degeneration and inflammatory reaction. The infiltration with leukocytes was only what would be expected as a result of the operative trauma. In another experiment in which the conditions were the same, the muscle



was normal at the end of seven days. In the three other experiments, the circulation in the extremity in which the muscle was isolated from all its arterial supply was further diminished by ligation of the iliac and hypogastric arteries. In each instance the isolated muscle was found completely absent, from seven to twelve days after operation.

In seventeen experiments, therefore, in which the arterial blood supply of an isolated muscle was obstructed, the muscle either retained wholly its normal physiologic and anatomic characteristics or it became completely necrotic and wholly disappeared. In no instance did the anemia result in an acute inflammatory process. In those experiments in which the muscle remained viable, it must have received its nutrition from the surrounding tissue or by a reversed circulation in its vein until the time of establishment of a new circulation by vessels growing in from the surrounding tissues. In some of those instances in which the large arteries of the extremity were ligated in addition to obstruction of the individual arterial supply of the muscle, the available supply of nutrition was so diminished that the isolated muscle did not survive the period of complete absence of arterial blood. Whether this was due to the diminution of the blood supply to the surrounding tissues, to the lowering of the pressure in the vein, or to a combination of both factors, is not clear. The importance, however, of the preservation of unobstructed veins to an extremity with a diminished blood supply has been demonstrated in some experimental work not included in this paper. It has been found that with an existing venous obstruction in an extremity gangrene is more likely to follow ligation of the large arteries of the extremity.

The importance of preservation of the patency of the vein is also suggested by the results obtained in the following experiments.

4 *Ligation of Both Artery and Vein*—In four experiments with the isolated muscle, both artery and vein were ligated, thus cutting the muscle free from all vascular connections. In two of these experiments the muscle showed no pathologic change at the end of periods of forty and one hundred and ten days. In two other similar experiments the muscle was found necrotic in one case in two days and in the other completely absent in twenty-one days.

5 *Experiments in Which the Vein Alone Was Ligated*—In nineteen experiments the isolated muscle was prepared and the vein alone was ligated leaving the artery and the nerve intact. These muscles were examined at the end of periods varying from one to one hundred and twenty days. In every instance marked pathologic changes were found.

Within an hour after operation the muscle becomes swollen, hard, and a dark blue. Stimulation of the muscle or nerve to the muscle

at this period usually gives a very slight contraction. At the end of twenty-four hours there is a tremendous extravasation of blood into the muscle and an accumulation of bloody fluid around the muscle. The muscle will bleed if cut. At forty-eight hours there is a marked accumulation of polymorphonuclear leukocytes about the muscle fibers. At this time many of the muscle fibers are clearly necrotic. In four days there is a marked connective tissue proliferation and extensive degeneration of muscle fibers. At ten days there is formed between the muscle fibers a large amount of connective tissue. There was usually muscle tissue in some amount at all periods at which muscles were examined, and whenever muscle fibers were present, some contraction could be demonstrated in the muscle. The progress of the fibrosis was in two instances so complete that no muscle tissue could be demonstrated in the isolated muscle. The marked inflammatory reaction and subsequent fibrosis always extended beyond the muscle and involved the surrounding tissues so that the muscle became embedded in a fibrous tissue mass. Contracture of the muscles was always present and in some instances the contracture of the single muscle was of such an amount as to prevent the normal flexion of the knee joint.

The details of the stages of the pathologic changes in the isolated muscle which followed occlusion of the vein are shown in the photomicrographs.

In these experiments in which a muscle was cut off from all circulation except that of a single artery and vein, and the vein was completely occluded leaving the artery intact, a constant pathologic change in the muscle resulted. This change was characterized by an initial period of acute inflammatory changes in the muscle and subsequently the development in the muscle of an extensive fibrosis. The fibrosis in some instances replaced a large portion of the muscle fibers and decreased very markedly the power of the muscle. In other instances the substitution of the muscle fibers by fibrous tissue was complete. The constancy of the pathologic process and the certainty with which it follows the experimental method described are important points.

#### SUMMARY

The results of these experiments are evidence for the statement of certain general conclusions as to the probable effect of the obstruction of the circulation of blood on the function of an extremity, particularly as it concerns the muscles.

The results of permanent obstruction of the principal artery or arteries to an extremity may be stated as follows:

1. There may be no demonstrable change in the anatomy or physiology of the extremity. This result, of course, only follows if

the circulation through the collateral anastomotic branches is *sufficient*. It is surprising indeed to find how small a collateral anastomotic arterial bed may prove *sufficient*.

2 A condition of ischemia in which there is no demonstrable anatomic change in the muscles may follow obstruction of the artery. After a period of voluntary muscle contractions, the extremity may become useless, in which state it remains only for a limited time. With rest the muscles again resume their function. This condition is probably a phenomenon of fatigue. In the dog the condition of ischemia always becomes less marked from day to day and ultimately disappears completely as far as could be observed in animals which were permitted the freedom of an "animal yard." It is possible that if some of the animals which had apparently recovered completely had been subjected to long-continued walking symptoms of ischemia would have become manifest. A state of chronic ischemia existing for years has been observed by Halsted in a man whose common iliac artery was ligated, and I have under observation a woman in whom one common iliac artery was ligated nine months ago who complains of weakness and cramps in her leg after walking "four blocks." It is worth while calling attention to the differences in ischemia after ligation of a large artery and that accompanying general arterial disease, the former always improves, while the latter may progress.

3 The permanent obstruction of the arterial supply of an extremity may result in gangrene. If gangrene develops it is more extensive in the skin than in the muscles. If the muscles are involved there is a tendency for the individual muscles to become totally necrotic or remain wholly viable. If a part of a muscle becomes gangrenous and part remains viable, the line of demarcation is sharp and coincides with the line of separation between the physiologically dead and physiologically living muscle. It is seemingly impossible to reduce the arterial supply to a muscle to a point where it is physiologically dead but anatomically alive. This is theoretically possible but practically impossible for the reasons that the limits of arterial blood supply which would be compatible with such a state must be proximate, and the blood supply to an extremity, particularly after ligation of its artery or arteries, must be continually changing. The results of temporary deprivation of the arterial blood supply to an extremity by temporary occlusion of arteries are less definite but more interesting.

It would seem from these experiments that although muscles stand better than skin a continued diminished blood supply, they stand less well a temporary absence of arterial blood. This is an important point which I do not believe has as yet been pointed out. Another fact which is to be emphasized is that after obstruction of an artery for a period of several hours and the subsequent removal of this

obstruction the pulse may return in the artery and all of its major branches and yet the circulation may not be reestablished in large areas of tissue

The temporary occlusion of the primary arteries of an extremity may, therefore, result in no demonstrable anatomic or physiologic change after the removal of the obstruction if the obstruction has existed only a few hours. If the obstruction exists longer there may be scattered foci of necrosis or degeneration of muscle or extensive massive necrosis of muscles and skin if the period of anemia is prolonged for as much as seventeen hours. This necrosis may take place in spite of a resumption of pulsation in all of the larger arteries of the extremity. The pathologic change in the muscles is associated with extensive edema and hemorrhage, but with a very slowly developing inflammatory reaction, and there is not a rapidly developing fibrosis and contracture of the muscles.

The experiments on the isolated muscle are in accord with the experiments in which the primary arteries of the extremity were ligated as regards the effect of diminishing the arterial supply to a muscle, that is the muscle either becomes wholly necrotic and disappears completely or remains wholly viable and shows no pathologic changes. The results of the obstruction of the vein of the isolated muscle with the preservation of the artery are different from any results obtained by artery occlusion. Under these conditions there was found a constant pathologic change, the outstanding features of which were hemorrhage, edema, degeneration of muscle fibers, and an acute inflammatory process which progressed to the more or less complete fibrosis of the muscle. This fibrosis is associated with contracture and loss of power of the muscle. The process may convert the muscle into a veritable fibrous mass which is incorporated in a similar fibrosis of the surrounding tissues. Simple hemorrhage in the muscle with or without interference with the arterial or nerve supply of the muscle does not cause a similar result.

The explanation of this pathologic process is one concerning which it is interesting to speculate. The slowing of the circulation is the first phenomenon observed in the process of inflammation. In blocking the veins the circulation is thus primarily slowed down and all of the succeeding manifestation of inflammation and repair follows. On the other hand a slowing of the circulation must follow an obstruction of an artery but inflammation does not result. It might be supposed that the venous obstruction asphyxiated the tissues and caused an accumulation of toxic waste products which damaged the muscle cells to the point of necrosis and the inflammation and repair processes follow the presence of this dead tissue. Were this true, a similar process should just as rapidly develop after temporary obstruction of the artery. Such is not the case. It, therefore, seems more likely that the initial

stimulus of the process is more mechanical than chemical. With the occluded vein and the open artery the pressure in the capillary system must rise above diastolic blood pressure. This pressure probably results in a more or less complete destruction of the entire capillary system. The destruction of the capillary system would certainly interfere with the nutrition of the tissues, and degeneration or necrosis of tissues might result. It would seem, however, that the acute inflammatory reaction and subsequent fibrous tissue formation were the result of the mechanical injury to the vascular system rather than the presence of degenerate or necrotic tissue. The magnitude of the reaction is certainly much greater than that seen about areas of necrosis.

The clinical application of these conclusions deserves some comment. A muscular weakness associated with a certain stiffness which follows the occlusion of a large artery may be a phenomenon of ischemia. Under such conditions one would not expect a complete paralysis and there would be no immediate manifestations of inflammation or contracture. This muscular weakness would be very likely to improve with the development of a more adequate collateral circulation. It would always be exaggerated by exertion and improve with rest. It is not associated with a fibrous transformation of the muscles. A complete muscular paralysis of any portion of the extremity which follows the occlusion of an artery is evidence of an anemia of the tissues incompatible with viability and usually signifies impending gangrene. With the development of gangrene the skin will almost certainly become necrotic to a higher level than the muscles. The permanent occlusion of a large artery is not followed by acute inflammatory disease. Anemia and inflammation are incompatible pathologic processes. *Any condition, therefore, which develops within twenty-four or forty-eight hours, and which is characterized by heat, swelling, pain, and a subsequent fibrosis cannot be the result of permanent occlusion of an artery.*

The phenomenon of edema of the tissues as a result of obstruction to an artery is interesting. Edema may follow obstruction of an artery. It is not constant either in amount, site of appearance, or time of appearance. In general, we believe edema follows the reestablishment of circulation in vessels to tissue which has already been damaged. Edema, therefore, follows the development of collateral circulation or the release of the original arterial block permitting blood to flow into tissue which previously had become in whole or in part degenerate. Edema does not make its appearance in tissues wholly deprived of blood nor in tissues in which the blood supply has remained adequate. It does appear in tissues between these extremes and is, therefore, found in the tissues near the line of demarcation in instances in which gangrene occurs, as a result of permanent occlusion of an artery, or in tissues

which have been deprived of blood completely for a limited period by the temporary occlusion of an artery. Keeping in mind this principle, therefore, it would seem that the time of appearance and the site of development of edema would be indicative of the development or nondevelopment of gangrene. For example, if the primary arteries of the posterior extremity were permanently occluded and edema of the thigh, and not of the leg, made its appearance in twenty-four hours, one could feel almost certain that the leg was to become gangrenous. On the other hand, if the edema made itself apparent in the foot at the end of twelve hours the chances of gangrene would be much less. In case of temporary occlusion of an artery the amount of edema would depend on the amount of tissue which had been damaged, and the extent of return of the circulation to the tissues in proximity to degenerate tissues.

The pathologic process following the marked obstruction to venous return of blood from tissues in which the arterial supply is not obstructed is of the nature of an inflammatory rather than a degenerative process. Degeneration or actual necrosis are present, but it is selective in nature and does not include all of the tissues of the muscle. The muscle fibers may in part degenerate or become entirely necrotic, but the interstitial connective tissue is stimulated to active proliferation and the processes of inflammation and repair completely overshadow the degenerative changes. Furthermore, the proliferation of the connective tissue elements when thus set going seems to continue for a period of several weeks, and the end-result is the transformation of the muscle into a mass of fibrous tissue. This process is one which sets in almost immediately after the venous occlusion and progresses with rapidity in the muscle leading to an early loss of function and contracture.

The pathologic changes following temporary occlusion of the primary arteries of an extremity have some of the characteristics of both those following permanent occlusion of the artery and those following occlusion of the vein. If the artery is occluded for a certain period the tissues of the extremity become degenerate in part. In other words, some tissues can remain viable without circulation for longer periods than others, or certain areas have their normal circulation or nutritive mechanism destroyed before other areas. If then the obstruction to the primary artery is removed and the blood flows back into the extremity, those tissues which have remained viable and retained their normal circulation or nutritive mechanism resume more or less their normal condition, while those tissues which have become necrotic, or had their normal circulation destroyed, become as foreign bodies in the living tissue. The living tissues react under such condition, and inflammation, absorption, and fibrosis follow. In the experiments which I have observed, however, in no case has the connective tissue reaction

been so marked as in those instances in which acute venous obstruction was produced. The degenerate areas have appeared to run the usual course of slow replacement by fibrous tissue as is seen in the usual anemic infarct.

That the classic picture of Volkmann's ischemic paralysis could only be explained on the basis of acute venous obstruction would seem quite clear. As a matter of fact, however, it is customary to refer to every case of contracture following the application of a tight bandage, tourniquet, plaster cast, or splint as Volkmann's ischemic contracture. Undoubtedly, some of these cases are due to pure local pressure necrosis, entirely analogous to the decubitus ulcer, or pressure sore on the heel or over the anterior superior iliac spine from continued pressure of a plaster cast. I have seen recently a patient in whom a fracture of the forearm which was treated by splints left in position for two weeks showed, after ten years, a marked contracture of the wrist in hyperextension and the thumb in a position of complete flexion and adduction across the palm. There was an extensive scar over the dorsal surface of the distal prominence of the radius and another deep scar where the end of the anterior splint rested in the palm. The patient gave a history of deep ulcerations being present when the splints were removed. In this patient there was marked atrophy of the extensor muscles of the forearm, but exploratory operation showed the tendons of these muscles incorporated in the deep scar on the dorsum of the wrist. The bellies of the muscles were soft and showed the normal nerve muscle reaction and no evidence of fibrosis. In such a case the continued pressure of a board splint against a bony prominence for two weeks with a local deep pressure necrosis is an entirely satisfactory explanation of the contracture.

In those instances in which a bandage or splint is applied to an extremity presumably never so tight as to obstruct immediately and completely the circulation distal to constriction, and in which there follows in the course of a few hours great pain and cyanosis which make the constriction no longer bearable, and in which removal of the splint is followed by swelling, heat, tenderness, and a rapidly developing contracture, one is forced to the assumption that the etiologic factor is either an acute venous obstruction or a temporary pressure anemia followed by a reestablishment of circulation through the damaged tissue. The ease with which the former is reproduced experimentally is evidence of its being the most important etiologic factor of contractures following the application of constricting dressings in the treatment of fractures. The reproduction of areas of degeneration and subsequent fibrosis of muscles by temporary anemia is so difficult experimentally that it is rather unlikely that the exact set of conditions for its causation would be present in any clinical instance.

## INTESTINAL ADENOMAS OF ENDOMETRIAL TYPE

THEIR IMPORTANCE AND THEIR RELATION TO OVARIAN  
HEMATOMAS OF ENDOMETRIAL TYPE (PERFORATING  
HEMORRHAGIC CYSTS OF THE OVARY) \*

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In a recent article I stated that I<sup>1</sup> believed that perforating hemorrhagic (chocolate) cysts of the ovary were hematomas of endometrial type, and that at the time of the perforation of the cyst some of the epithelium lining it might be carried with the contents of the cyst into the peritoneal cavity. This epithelium might become lodged on the surface of the peritoneum, soiled by the contents of the cyst, and there develop into adenomas of endometrial type. The adenomas arising from the implantation of this epithelium might be small and quiescent, or they might become invasive, giving rise to so-called adenomyomas of the part invaded. I compared the conditions arising from the perforation of these cysts with the implantations of ovarian papilloma and cancer resulting from the rupture or perforation of an ovarian tumor containing these growths. These cysts were described as developing most frequently in women between 30 years of age and the menopause. In the forty-nine cases studied up to this date (Nov 25, 1921) only four patients were under 30 years of age, the youngest being 23 (the other three were 28). I have encountered only one instance in a patient after the menopause. In this case the remains of an undoubted ovarian hematoma of endometrial type, with its associated implantation adenomas, were found.

The size of these hematomas was described in the previous paper as being usually between 2 and 4 cm in diameter, occasionally less

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\* From the gynecologic and pathologic departments of the Albany Hospital and the Albany Medical College.

1 Sampson, J A. Perforating Hemorrhagic (Chocolate) Cysts of the Ovary, Arch Surg 3 245-323 (Sept) 1921.



than 2 cm and also occasionally larger than 4 cm. Since I have learned to recognize the early stages in the development of this condition and likewise some of the later stages in their retrogression, I have been able to detect specimens which previously would have been overlooked. I would modify the foregoing statement in regard to their size by adding that they are often so small and inconspicuous that they may be easily missed both at the time of the operation and in the pathologic laboratory. The hemorrhage or pigmentation, the result of previous hemorrhage, in the ovarian tissue about the smaller cysts or extending into their lumina will usually call one's attention to an abnormal condition of the ovary. The histologic examination of this area will show whether or not a gland, tubule or small cyst of endometrial type is present.

In discussing the frequency of this condition, I stated that during the year, May 1, 1920, to May 1, 1921, I had found perforating hemorrhagic cysts of the ovary in fourteen of 178 patients between 30 and 50 years of age who had had an abdominal operation for some disease of the pelvic organs. Since I have learned to recognize the earlier and also the later stages of this condition, I have reviewed some of the questionable specimens removed during that year and have been able to add four more cases to the fourteen. During the last six operative months, I have encountered nineteen cases of perforating hemorrhagic cysts of the ovary in my practice. The amount of my operative work has not increased and I do not believe the frequency of this condition has, but I am better able to recognize it, both during the operation and in the systematic study of the specimens afterward. It is a common condition, probably present in from 10 to 20 per cent of women between 30 years of age and the menopause who require an abdominal operation for some disease of the pelvic organs.

At operation the cyst or ovary is usually adherent, and in freeing it the "chocolate" contents escape because a previous perforation, which has been sealed by whatever structure the ovary or cyst has become adherent to, is reopened or the cyst is torn. Adhesions and other signs of implantation are present if a perforation has occurred, and these vary greatly in location and extent. They are found where the contents from the perforation of such a cyst would be likely to fall, as in any of the natural pockets and folds of the pelvis and on any of the structures situated in the pelvis at the time of perforation and especially in the bottom of the culdesac. One would suppose that the rectum, sigmoid, terminal loop of the ileum and the appendix would frequently be invaded by these adenomas. This is true as will be shown later in this communication.

THE INCIDENCE OF ADENOMAS OF ENDOMETRIAL TYPE OF  
THE INTESTINE AND THEIR RELATION TO OVARIAN  
HEMATOMAS OF ENDOMETRIAL TYPE

My attention was first directed to a so-called adenomyoma of the intestine in the year 1909 (Case 1) February 10 of that year, I operated on a woman, 36 years of age, the preoperative diagnosis being a tubal inflammatory disease of the left side and a weakened pelvic floor. On exposing the pelvic contents, the left ovary was found to be cystic and densely adherent. I removed the left tube and ovary and then noticed that there was an indurated area in the wall of the sigmoid, just below the pelvic brim, which was diagnosed

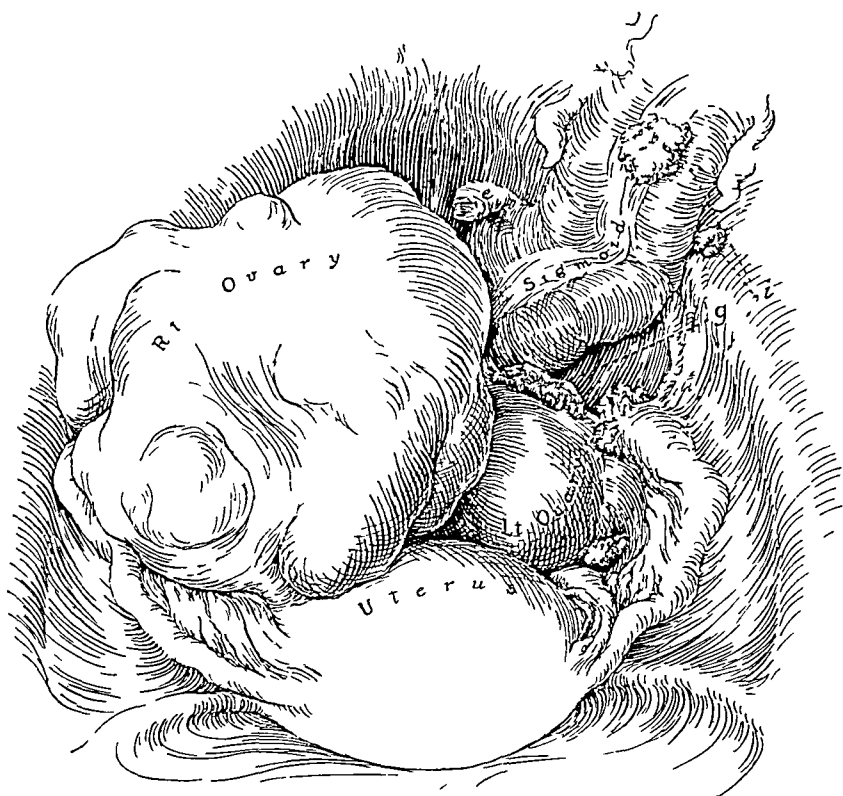


Fig 1—Implantation carcinoma of the sigmoid secondary to the perforation of a carcinomatous cyst of the right ovary, bilateral ovarian carcinoma. View of the pelvic contents from above,  $\times \frac{2}{3}$ . The implantations (*i*) are shown on the anterior surface of the sigmoid, its mesentery, on the posterior surface of the left broad ligament, and also involving an epiploic appendage (*e*). The growth (*g*) on the surface of the left ovary may have been an implantation from the right ovary or a direct extension through the wall of the left ovary. A perforation had occurred through the lateral and lower wall of the right ovarian cyst and this had been sealed by the pelvic wall, to which it had become adherent. The left ovarian tumor, about as large as the right, filled the culdesac and only a small portion of it is shown in this illustration. Compare Figure 2.

as a carcinoma of this part of the bowel. About 8 cm of the intestine, including this area, was resected and the intestine was repaired by an end-to-end anastomosis. A section of the intestine showed a typical adenoma of endometrial type, apparently invading the sigmoid from its serous surface (Fig 46). The cystic ovary was not examined microscopically and no mention was made in the operative notes of the presence of an ovarian hematoma. In only one of the twenty-three cases reported in my recent paper was a portion of the intestine removed (Case 19 of that series and Case 2 of the present series). The histologic findings in the section of the sigmoid removed in this case are shown in Figure 42 and are similar to those found in the preceding one. With my present knowledge of the subject, I believe that had I examined carefully the portions of the intestine in the pelvis in the twenty-three cases mentioned above and had it

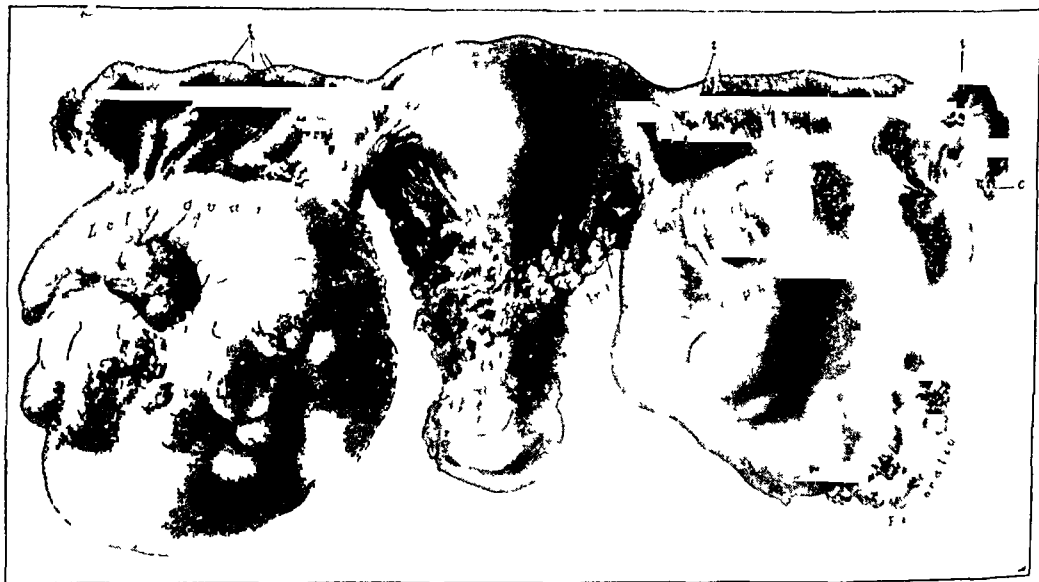


Fig 2—Bilateral ovarian carcinoma with perforation of the right carcinomatous ovarian cyst and implantations on the posterior layer of both broad ligaments, the fallopian tubes and the posterior wall of the uterus. Posterior view of the uterus, tubes and ovaries shown in Figure 1,  $\times \frac{1}{2}$ . The implantations (*i*) on the posterior layers of the broad ligaments are shown (Compare with Figs 13 and 19). The implantation involving the distal portion of the right tube had penetrated the wall of the tube and is protruding through its fimbriated opening (*c*). Implantations (*imp*) are present on the posterior wall of the uterus (Compare with Figs 13 and 28). The growth (*g*) was referred to in Figure 1. In places the carcinoma resembled an adenocarcinoma of the uterine mucosa. Some of the cells were ciliated. I believe this tumor may have arisen from misplaced "endometrial" epithelium in the ovary, just as ovarian hematomas of endometrial type arise from this epithelium. Ovarian carcinomas with their secondary peritoneal implantations are a well recognized pathologic entity and also a well recognized clinical entity which can often be diagnosed prior to operation.

been possible to examine histologically the portion of the rectum which was adherent to the posterior wall of the cervix and uterus, adenoma of endometrial type would have been found in a large percentage of these cases. In the nineteen cases of ovarian hematomas in which I have operated since the above mentioned series, adenoma of endometrial type, involving some portion of the intestinal tract, was found in eight instances, and I believe that had it been feasible to examine histologically the portion of the rectum adherent to the cervix or uterus in some of the others adenoma invading the rectum

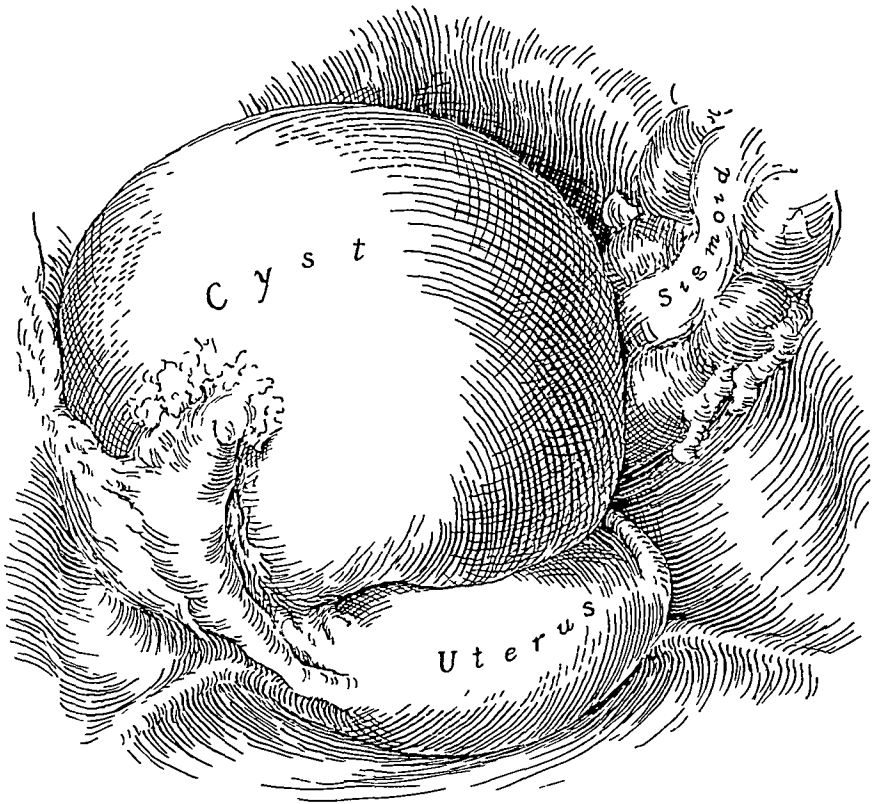


Fig 3 (Case 4) —Perforated hematoma (hemorrhagic cyst) of endometrial type of the right ovary. View of the pelvic contents from above,  $\times \frac{2}{3}$ . The ovarian cyst filled the pelvis. A perforation had occurred through the lower wall of the cyst and this had been sealed by the posterior surface of the right broad ligament to which it had become adherent. On freeing the right ovary, the cyst was torn or the perforation reopened and a large amount of "chocolate" fluid escaped. Compare Figure 4.

would have been found in some of these. This small series of nineteen cases suggests that implantation adenoma of endometrial type of some portion of the intestinal tract may be present in at least one half of the cases of perforated ovarian hematoma of endometrial type with peritoneal implantations. If this type of ovarian hema-

toma occurs in from 10 to 20 per cent of women between 30 years of age and the menopause that require an abdominal operation for some pelvic disease, then endometrial adenoma of the intestines is quite a common condition. On account of its frequency, pathologic and clinical importance, it deserves a greater recognition than has



Fig 4 (Case 4) —Implantation adenoma (of endometrial type) of the sigmoid, posterior surface of the uterus, left tube and left ovary, and a large hematoma (of endometrial type) of the right ovary with evidence of a previous perforation. Condition found at operation after ligating and cutting the ovarian vessels and drawing the uterus upward and forward,  $\times 5\%$ . An indentation of the sigmoid with thickening of its wall is shown at *c* (Compare Fig 5). A hemorrhagic cyst on the surface of the mesentery of the sigmoid with induration of the underlying tissue is indicated at *a* (Compare Fig 8). The epiploic appendages (*b*) are thickened and contracted (Compare Figs 6 and 7). The perforation *p* in the hematoma of the right ovary is shown and also implantations (*t*) in the left tube. The distribution of the involvement of the sigmoid is similar to that shown in Figure 1. For a description of the right ovarian cyst and the implantations on the posterior surface of the uterus and tube, compare Figures 9, 10, 11 and 12.

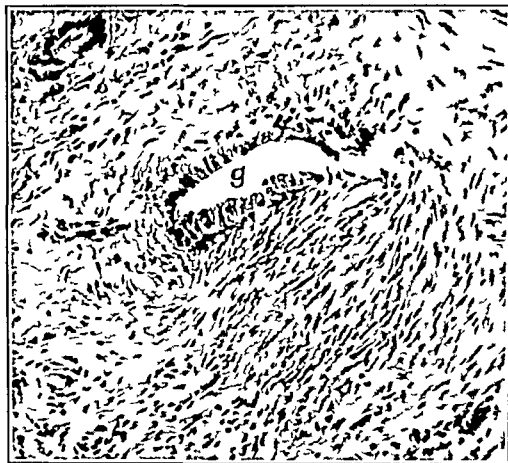


Fig 5 (Case 4) —Adenoma (of endometrial type) in the wall of the sigmoid. A small wedge-shaped piece was excised from the indurated wall of the sigmoid shown at *c*, Figure 4. Photomicrograph shows a glandlike space (*g*) lined by columnar epithelial cells resembling those of the endometrium.

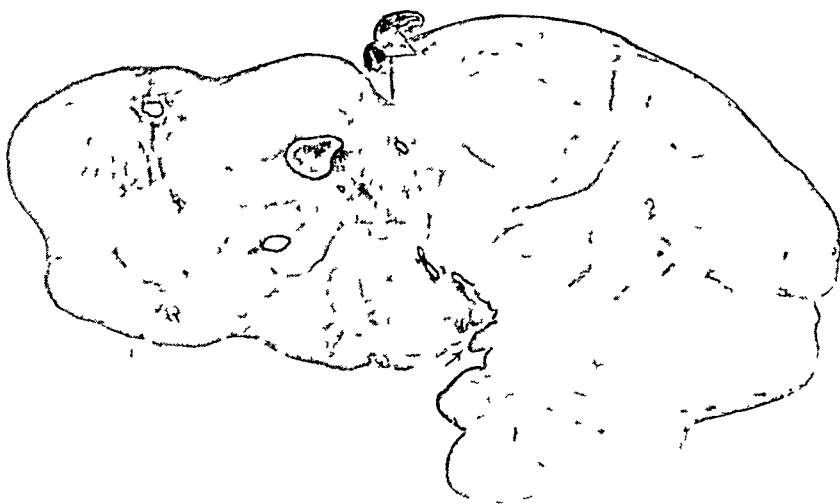


Fig 6 (Case 4) —Adenoma (of endometrial type) of an epiploic appendix. Cross section,  $\times 10$ , of one of the epiploic appendages shown at *b*, Figure 4. The adenoma has apparently invaded the appendix in the depression indicated by the arrow and has extended through the appendix appearing on the opposite side as an endometrial polyp (*e*). The marked increase in the connective tissue about the adenoma may be noted.

been accorded it in the past. The question naturally arises, Do all cases of this type of adenoma of the intestines arise from the implantation of the epithelial contents of a perforated ovarian hematoma of endometrial type? The twelve cases of this type of intestinal adenoma which I have studied were all associated with an ovarian hematoma (not positively proved in one case) and could have arisen from them. The ovarian hematomas may be very small (Fig 52), and in the retrogressive changes due to repeated hemorrhage and loss of their epithelial lining, the remains of the smaller ones may become very inconspicuous (Fig 51), or they may even entirely disappear. For these reasons it is difficult to rule out the ovary as a source of the



Fig 7 (Case 4) —Photomicrograph of adenoma (of endometrial type) of an epiploic appendage at the apparent portal of invasion. The arrow indicates the portal of invasion. The appearance of the tissues at this place suggests that the epithelium originally implanted on the appendage had died out, this, together with the increase in the connective tissue, causes the retracted condition. The glandlike spaces and tubules are lined by columnar epithelium similar to that found in the endometrium and also that lining the perforated ovarian hematoma (Fig 11).

implantations, even though the ovaries appear normal. However, I believe that they may also arise from a source other than ovarian hematomas, as will be discussed later in this paper.

#### PATHOLOGIC ANATOMY

Implantation carcinoma of the various organs and structures of the peritoneal cavity is well recognized both by pathologists and clinicians and likewise the important part played by ovarian carci-

noma as a source of these implantations. Implantation adenomas of endometrial type are analogous to those of carcinoma, and I believe that ovarian hematomas of endometrial type with perforation are a frequent, possibly the principal, source of these implantations. The implantations, as in those of ovarian carcinoma, are found where the contents escaping from the perforation of such a hematoma would be likely to fall, as on any of the structures found in the pelvis and especially in the culdesac. As already stated, we would expect that the portions of the intestinal tract normally found in the pelvis would often

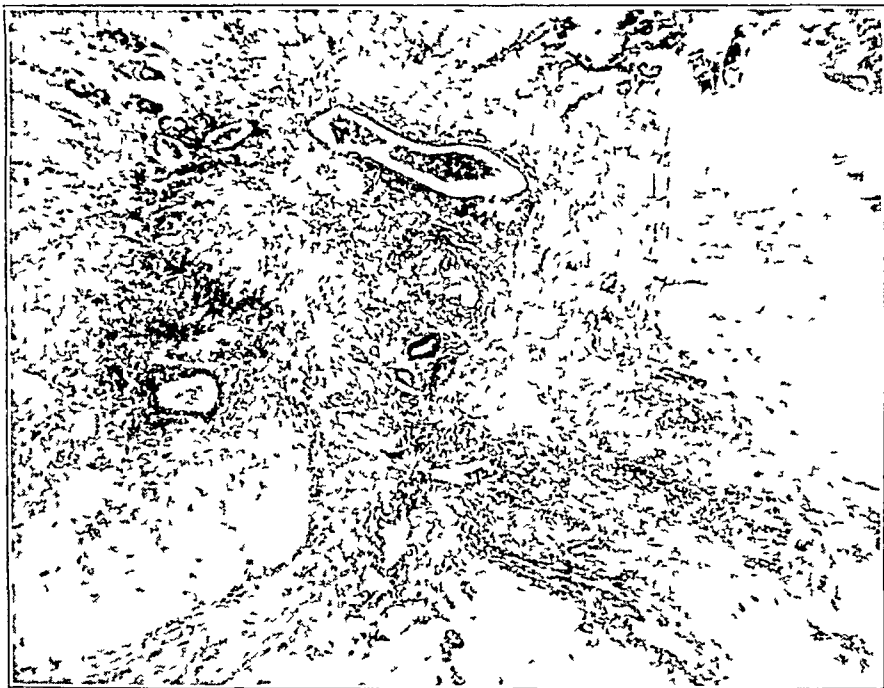


Fig 8 (Case 4)—Implantation adenoma (of endometrial type) invading the mesentery of the sigmoid. I believe the hemorrhagic bleb (Fig 4 a) was encysted menstrual blood from the underlying adenoma which is shown in this photomicrograph. The glandlike structures are of endometrial type, with evidence of hemorrhage (menstrual) into the tissues about them and into the lumina of some of the glands. The reaction of the surrounding tissue is similar to that shown in Figure 7.

be the seat of these implantations. I believe that implantations are often present on the rectum, sigmoid, small intestine and appendix. In the twelve cases reported in this communication the rectum and the sigmoid, including the epiploic appendages and their mesentery, were involved in eight, the appendix in four and the small intestine in two. It is interesting to note that of the eight instances of implantation on the sigmoid and rectum the ovarian hematoma was situated in the left ovary in six, while of the four instances of implantation on the



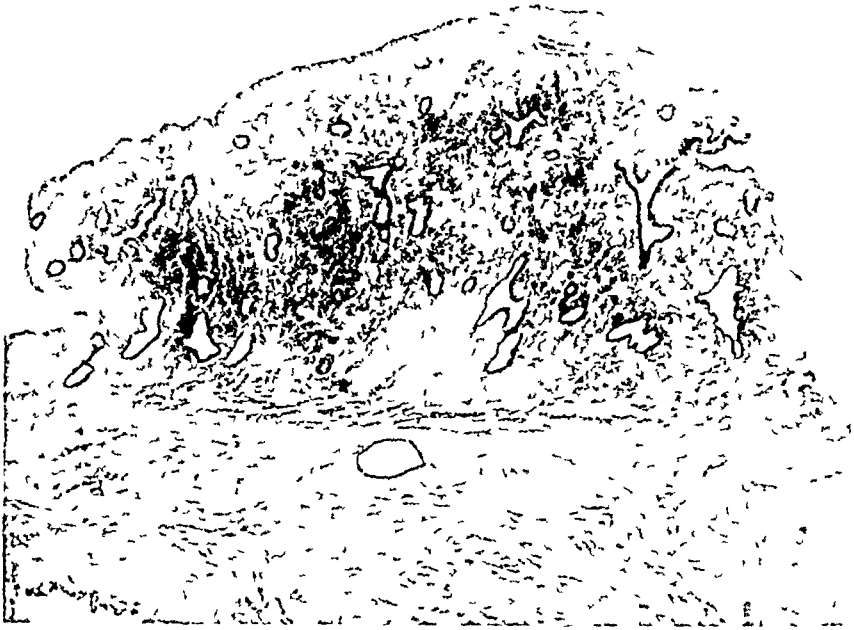


Fig 9 (Case 4) —Photomicrograph of an implantation adenoma (of endometrial type) on the surface of the left tube (Fig 4 *t*) Histologically, it resembles normal endometrium. It is analogous to the implantation carcinoma shown in Figure 2

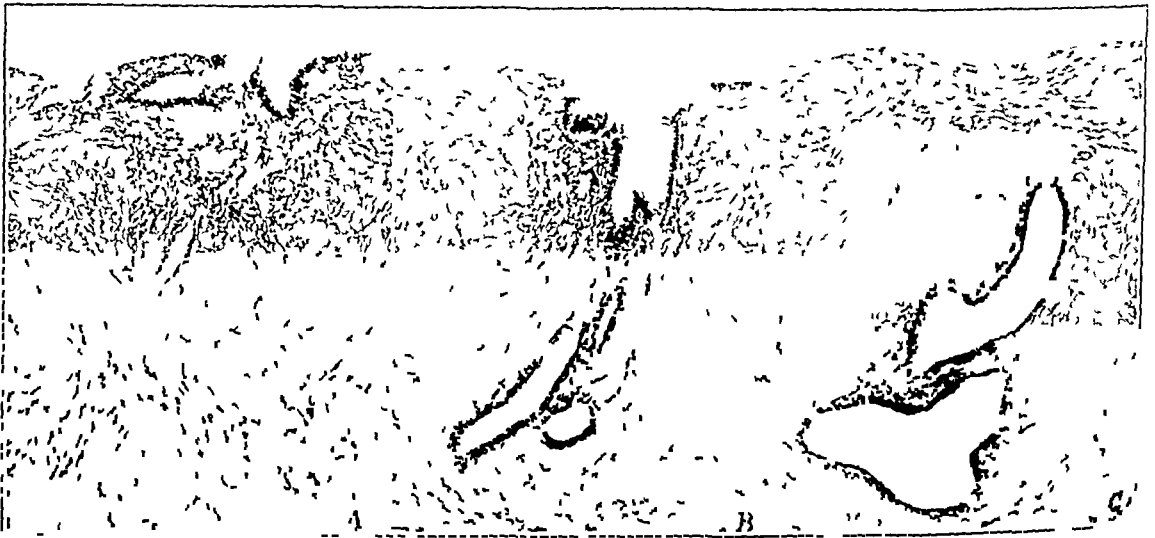


Fig 10 (Case 4) —The invasion of the posterior uterine wall from the implantation of adenoma (of endometrial type) on its surface (Fig 13 *c*) Photomicrographs of serial sections (some sections purposely not shown) *A* shows the adenoma on the surface, *B*, its invasion of the uterine wall, and *C*, tubules or glands in the uterine wall beyond the implanted area giving rise to a so-called adenomyoma of the uterus. I believe that this adenoma of the uterus did not arise from the direct invasion of the uterine mucosa of the uterine cavity or from developmental inclusions of müllerian epithelium or from a metaplasia of the peritoneal mesothelium, but I believe it arose from the implantation of epithelium from the lining of a hemorrhagic cyst of the ovary which had perforated (Compare Figs 11 and 12)

appendix the ovarian hematoma was situated in the right ovary in all four. This suggests that while the intestinal implantations from either ovary may be general in their pelvic distribution the portion of the intestine usually situated near that ovary is more likely to be involved.

The character of the lesions varies greatly, most of them are insignificant and chiefly of histologic interest, but even these carry with them the possibility of invasion, coupled with that of function, namely, periodic hemorrhage (menstruation). The menstrual blood may be unable to escape and is retained in the tissues surrounding the adenoma or in its lumen. In other instances the menstrual blood escapes into the peritoneal cavity, possibly carrying with it epithelial cells which may give rise to further implantations, just as the implantations arose from the original source. The adenoma then may spread



Fig 11 (Case 4)—Photomicrograph of a section of the wall of the perforated hematoma (of endometrial type) of the right ovary. The cyst or hematoma is lined by cuboidal to columnar epithelium, with evidence of hemorrhage into the underlying ovarian stroma just as in menstruating uterine mucosa. Histologically, the epithelium lining the hematoma is similar to that lining the glands and tubules in the implantations. The escape of this blood into the cavity of the hematoma would carry with it some of the overlying epithelium (absent in places), and the escape of the contents of the cyst through the perforation might carry some of these epithelial cells into the peritoneal cavity, and wherever they might lodge peritoneal implantations might arise just as in ovarian carcinoma. I believe this was the origin of the majority (possibly all) of the implantation adenomas shown in the illustrations of this case.

from the implantations both by growth by continuity and by implantations. In other instances, the implantation adenoma is of great clinical importance, that is, when it involves some portion of the intestinal tract in such a way as to interfere with its function. The disturbance of function is then a mechanical one, as in carcinoma, namely, that

of obstruction, and the obstruction in endometrial adenoma may be due to three factors first, the constriction of the lumen of the bowel by the growth and especially by the marked hypertrophy of the tissues surrounding the adenoma (Fig 54), second, by kinking the intestine, evident in Figure 4, and third, by the accumulation of menstrual blood in the adenoma causing hematomas (Fig 42) The symptoms of obstruction may be more marked during the menstrual period, as at that time more blood may escape into the adenoma situated in the wall of the intestine (Cases 2, 4 and 8) The various lesions found in the intestinal tract are similar to those implanted on other pelvic structures, such as the uterus with its adnexa and

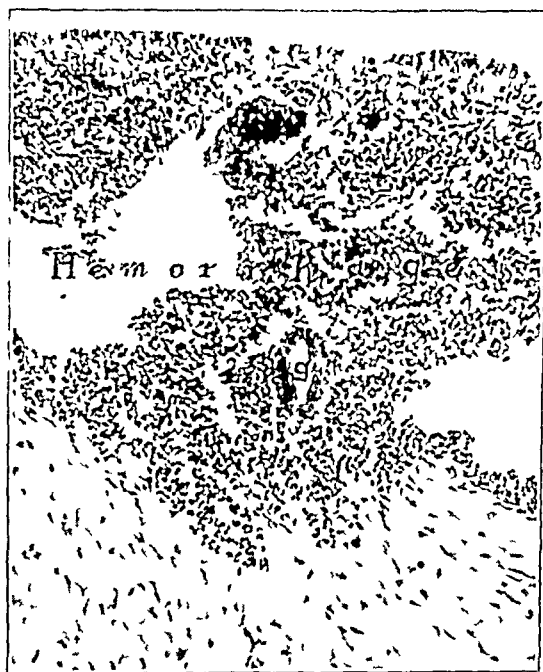


Fig 12 (Case 4) —Photomicrograph of the cyst wall showing an extensive stromal hemorrhage with loss of some of the surface epithelium which has been carried by the hemorrhage into the cavity of the cyst and into the peritoneal cavity through the perforation. A gland (*g*) of endometrial type is present in the stroma.

ligaments. The latter are much easier to study histologically, as they may be more safely removed. The implantation begins with the deposit of epithelium on the peritoneal surface of these structures. This epithelium sinks into the underlying tissues, and, true to its type, forms glands and tubules as shown in the previous communication. In some instances, a localized growth of endometrial mucosa arises like a polyp which may be sessile or pedunculated, simulating the polyps found in the uterine cavity. In other instances the tubules invade the underlying tissue with very little evidence of the growth

on the surface. The epithelium originally implanted may "die out" or may be covered with adhesions so that in some of the older lesions it may be impossible to determine the exact site of the original implantation. The tubules often burrow through the tissues in many directions and the portal of entry, if still present, may only be determined by cutting many sections, or better still by cutting serial sections (Fig 10)

I have made the following classification of these implantations. It is somewhat artificial, as all gradations between the groups may

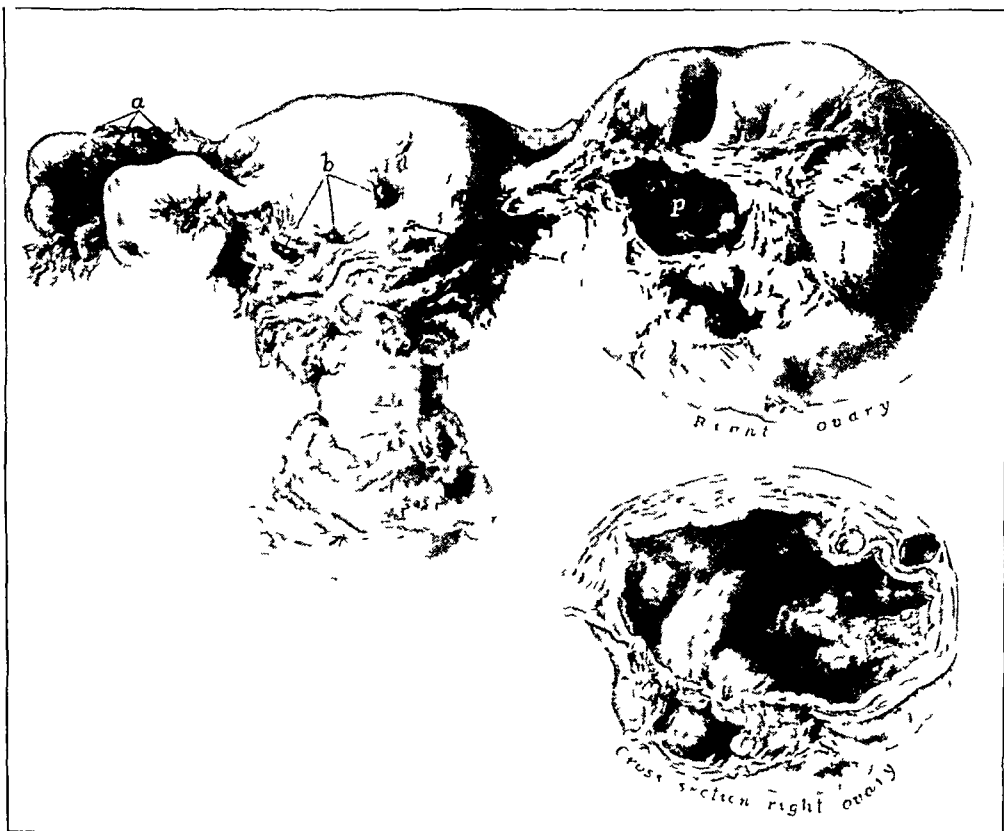


Fig 13 (Case 4)—Perforated hematoma (of endometrial type) of the right ovary, with implantation adenomas (of endometrial type) on the posterior surface of the left tube (*a*), the uterus (*b* and *c*), the left ovary and the sigmoid, including its mesentery and epiploic appendages (Fig 4). Posterior surface of the uterus and tubes and under surface of the ovaries,  $\times \frac{2}{3}$ . Compare with Figure 2. A perforated hematoma (of endometrial type) of the ovary with its peritoneal implantations is a pathologic entity as definite as that of ovarian carcinoma with its implantations and also a clinical entity which can often be diagnosed prior to operation (Compare histories of Cases 4, 8, 10, 11 and 12).

be found and more than one group may be present in the same case (1) surface and superficial implantations, (2) implantations developing between adherent folds of peritoneum or other adherent structures,

well seen in the culdesac between the rectum and uterus (pocketed implantations), (3) the deep invasion of the adenoma into the underlying structure

1 Surface and Superficial Implantations These probably form the largest group

(a) The most frequent lesion in this group is the presence of sub-peritoneal glands and tubules of endometrial type, usually with evidence of hemorrhage into the surrounding tissue or into the lumen of the glands or tubules The surface of the intestine or structure

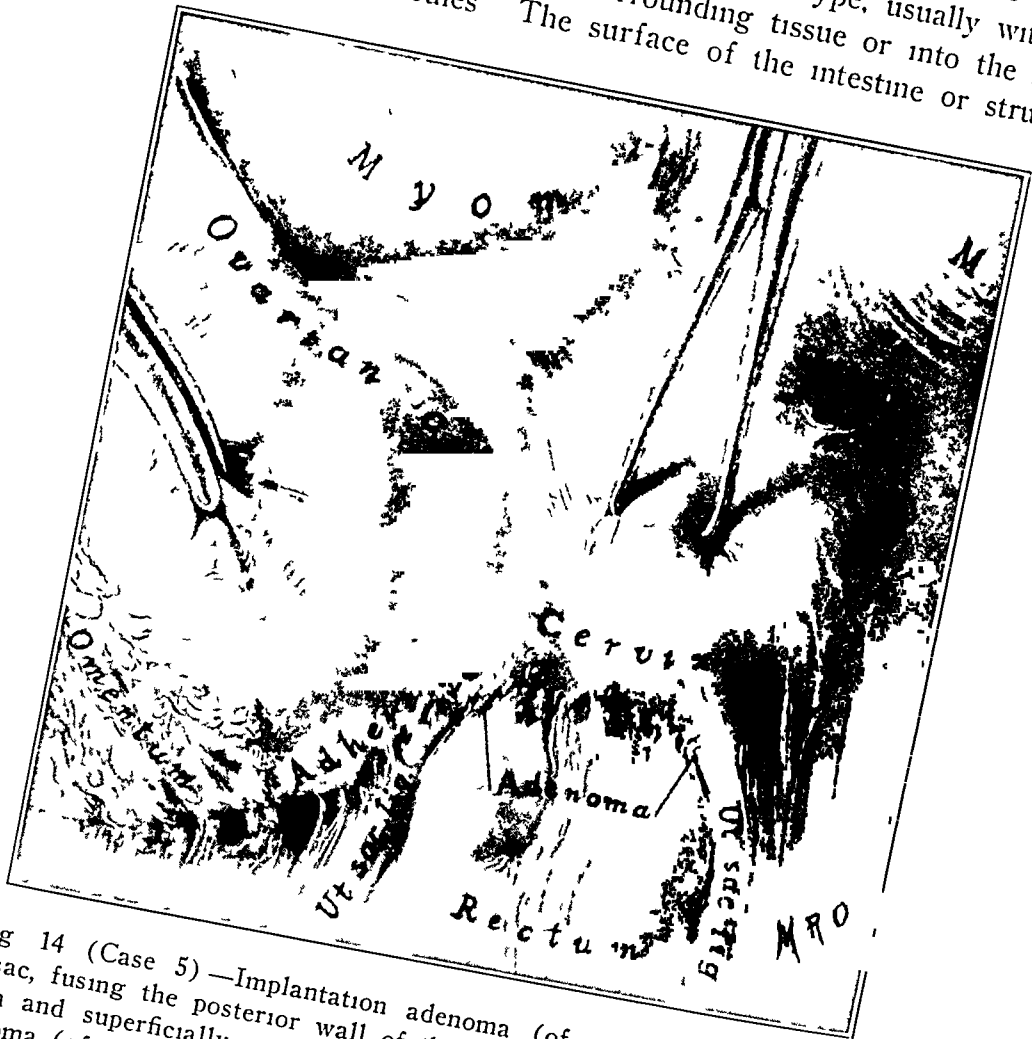


Fig 14 (Case 5) —Implantation adenoma (of endometrial type) in the culdesac, fusing the posterior wall of the cervix to the anterior wall of the rectum and superficially invading both the cervix and the rectum, a large hematoma (of endometrial type) of the left ovary with evidence of a previous perforation multiple leiomyomas of the uterus Condition found at the operation (natural size) The cervix is drawn upward by a tenaculum, showing the rectum fused to the cervix and carried with the latter in a characteristic manner Small pigmented blebs were present on the posterior surface of the cervix and the anterior wall of the rectum along the line of their fusion The ovarian cyst is shown adherent to the bottom of the pelvis and the tip of the omentum was drawn down by these adhesions When the cyst was freed, its wall was torn or the perforation was reopened and a large amount of chocolate fluid escaped

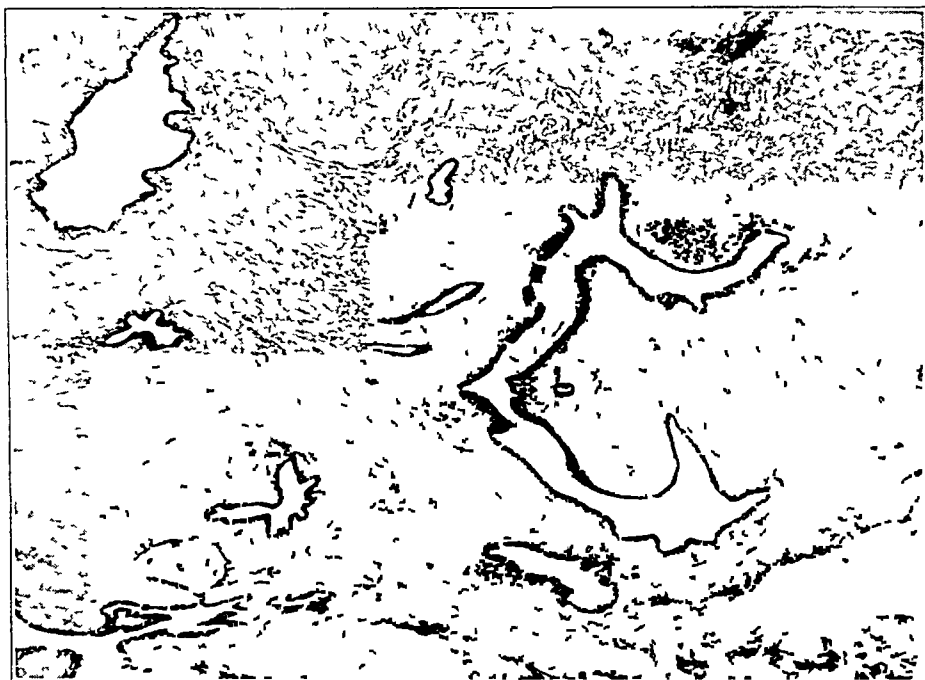


Fig 15 (Case 5)—Photomicrograph of a section from the posterior wall of the cervix showing the collapsed glands and dilated tubules of endometrial type which prior to the operation were filled with retained blood (menstrual)



Fig 16 (Case 5)—Photomicrograph (low power) of a portion of the wall of the ovarian hematoma near its hilum. This shows that the surface epithelium is for the most part lacking. Some of the epithelium, however, is still present in depressions (*d*), and glandlike structures (*g*) are also situated in the deeper portions of the ovarian tissue lining the hematoma. Histologically, these structures are similar to uterine glands and also to the glandlike structures shown in Figure 15. Epithelium was found only in sections taken from the upper part of the hematoma.

involved is thickened and the brown pigmented dots (1 to 2 mm in diameter) and larger elevated areas due to the above mentioned menstrual hemorrhage may be easily detected at operation (Figs 19, 20, 21 and 22)

(b) Endometrial tissue on the surface of the intestine including polyps The epithelium deposited on the peritoneal surface may form typical endometrial tissue The growth is often small and insignificant and at times typical endometrial polyps may develop (Fig 33 and 49)



Fig 17 (Case 5) —Photomicrograph (high power) of one of the depressions with an epithelial lining shown in Figure 16 It is lined by low to columnar epithelium of endometrial type, the columnar epithelium prevailing The tissue surrounding this depression is composed mostly of pigmented cells of the type of endothelial leukocytes which formed the greater part of the lining of the hematoma

(c) Larger subperitoneal hematomas, a later stage of the lesion mentioned in *a*, may arise from the retention of the menstrual blood in the lumen of the dilated glands or tubules (Figs 37 and 38)

(d) Blood escaping from these implantations may become encysted and form small hemorrhagic blebs (Fig 26)

2 Implantations Developing Between Adherent Folds of Peritoneum or Other Adherent Structures (Pocketed Implantations) The parts involved become fused, and on separating them the surface of

the freed structures often presents a characteristic "pitted" appearance, due to the exposure of the endometrial tissue in the pockets between the adhesions or in the tissues of the organ invaded (Figs 27, 28, 29 and 30)

3 The Deep Invasion of the Adenoma into the Underlying Structures The tubules may worm their way into the tissues of the

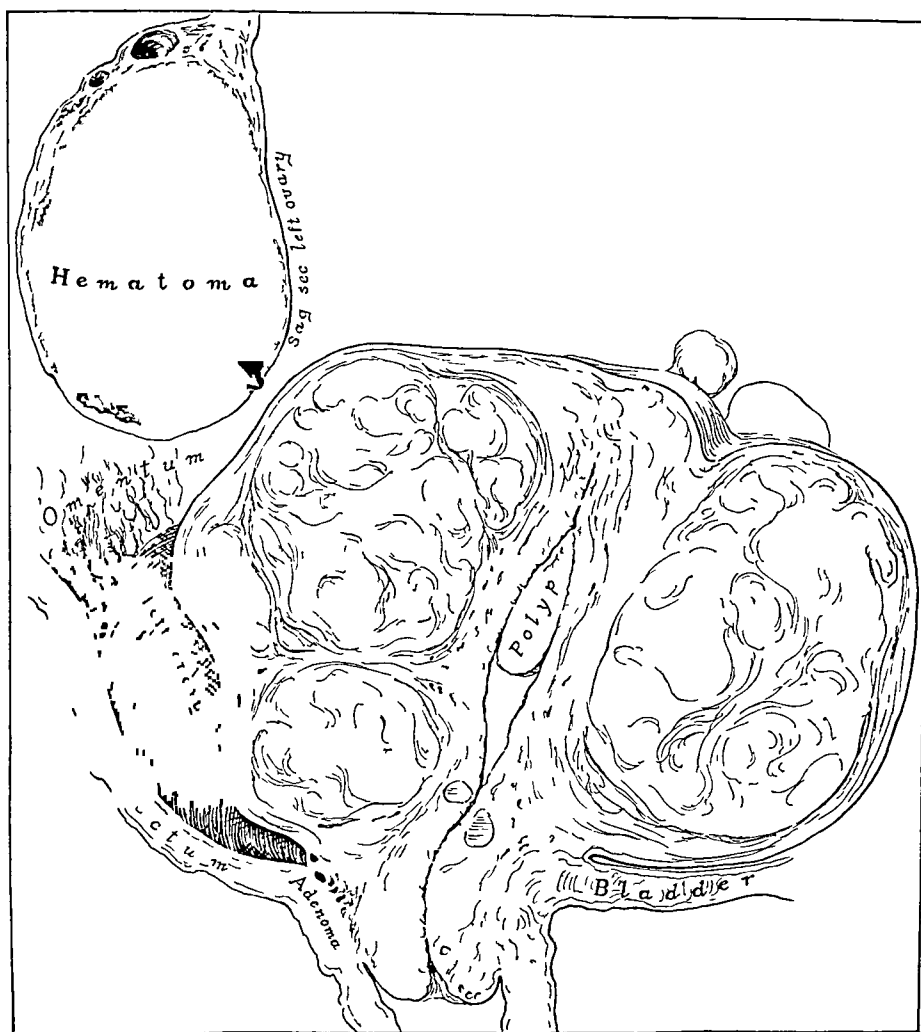


Fig 18 (Case 5)—Sagittal section of the myomatous uterus and adjacent pelvic structures indicating the condition present prior to the operation. The adenoma of endometrial type is shown fusing the cervix to the rectum and superficially invading these structures. The ovarian hematoma or hemorrhagic cyst is shown both in situ and also in sagittal section, with evidence of a previous perforation, indicated by the arrow. The diagnosis is evident—an ovarian hematoma of endometrial type with perforation and the escape of some of its epithelium into the culdesac and the subsequent growth of this epithelium giving rise to an adenoma of endometrial type in this situation as in an ovarian carcinoma with perforation.



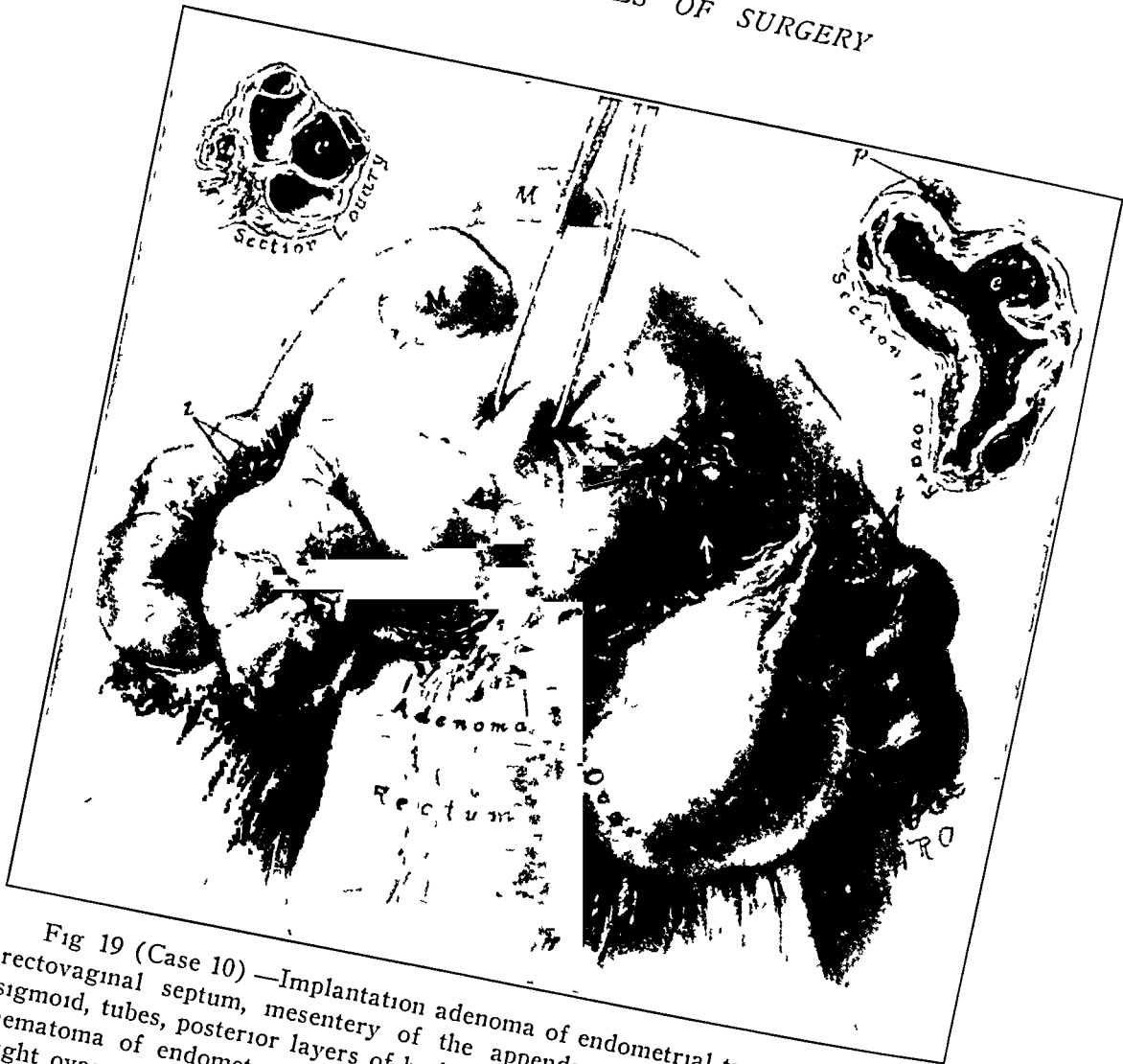


Fig 19 (Case 10)—Implantation adenoma of endometrial type of the rectum, rectovaginal septum, mesentery of the appendix, epiploic appendage of the sigmoid, tubes, posterior layers of both broad ligaments, posterior uterine wall, hematoma of endometrial type of the left ovary (not perforated) and of the right ovary perforated, multiple leiomyomas. Posterior view of the uterus and appendages as they appeared at the operation,  $\times 5/8$ . The ovaries are also shown in cross section. On drawing the uterus upward, the rectum is carried with it because it is fused to the posterior wall of the cervix and the lower portion of the body of the uterus. The characteristic lesions are shown on the wall of the rectum above its fusion with the uterus. Implantation adenoma of the uterus is shown at *Ad*, at *H* an endometrial hematoma is situated in the uterine wall (Fig 23). The implantations (*i*) are shown on the posterior surface of both broad ligaments. The left ovary was not adherent and a non-perforated hematoma of endometrial type is shown in the cross-section of this ovary at *c*. The right ovary was densely adherent to the posterior surface of the uterus. When it was freed, "chocolate" fluid escaped, because a previous perforation had occurred (indicated by arrow and *p*). The right ovary is shown in cross-section (collapsed), compare Figure 24.



Fig 20 (Case 10) —Appendix and portion of an epiploic appendage of the sigmoid (natural size) An implantation adenoma of endometrial type is present in the mesentery of the appendix at *A* (Compare Fig 21) The appearance of the characteristic lesions of the epiploic appendage is shown in *Ep app* (Compare Fig 22)



Fig 21 (Case 10) —Cross-section of the appendix and its mesentery through the adenoma with hemorrhage (*h*) into the tissue about it (Compare Fig 20 *A*) Histologically, it is similar to those shown in Figure 22 *L* is a small lymph node



Fig 22 (Case 10) —Photomicrograph of a section of the epiploic appendage shown in Figure 20 This shows a characteristic lesion with evidence of hemorrhage in the lumen of the dilated glands and also in tissue about them, thus causing the pigmented elevations shown in Figure 20

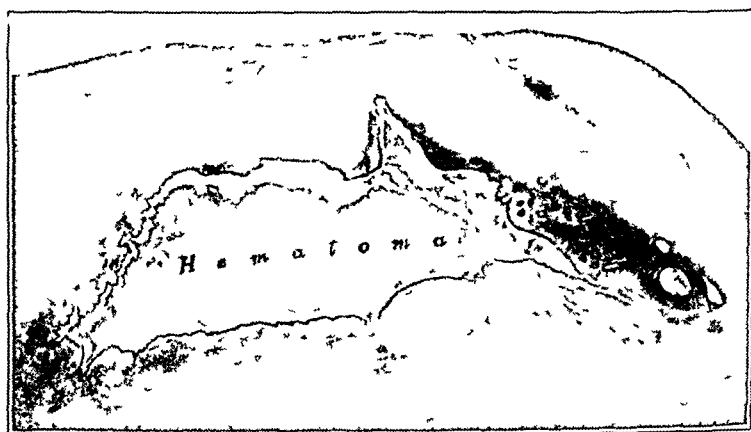


Fig 23 (Case 10) —Hematoma of endometrial type in the posterior uterine wall at H, Figure 19 I believe it arose from an implantation adenoma of endometrial type as shown in Figure 10, and that the blood is menstrual What is the source of the implantation adenomas shown in this and previous illustrations of this case? They could have arisen from the perforated hematoma of the right ovary shown in Figure 19 (Compare Figure 24)

intestine often associated with a marked thickening of the muscle and connective tissue (Figs 6, 54 and 55) At other times there is very little reaction Many varieties of "endometrial" tissue and its derivatives are found, such as glands and tubules, with and without a characteristic uterine stroma, dilated tubules with flattening of the epithelium (Figs 42 and 43), miniature uterine cavities (Fig 43), hematomas due to the retention of menstrual blood (Figs 42 and 46) and structures resembling the mucosa of the fallopian tube

The invasion of the rectum is usually associated with a thickening of the rectal wall easily detected on rectal palpation Sometimes the growth extends downward, between the rectum and the vagina, forming a tumor mass also easily felt on both vaginal and rectal

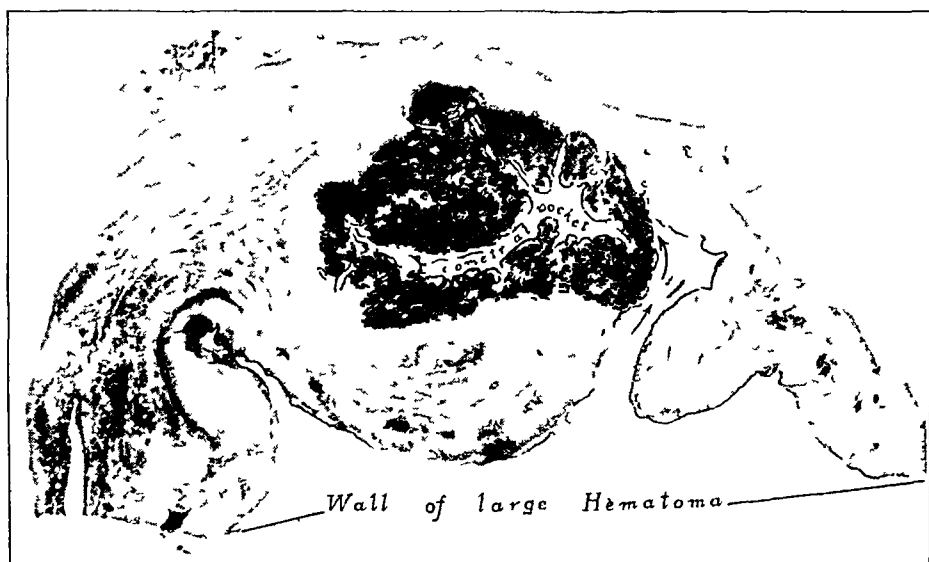


Fig 24 (Case 10) —Section of the wall of the perforated hematoma of the right ovary through the pocket *c*, Figure 19 It is lined in places by epithelium of endometrial type, some of which has been carried away by the underlying hemorrhage and out through the perforation into the peritoneal cavity, thus giving rise to the implantations The pocket is lined by endometrial tissue as characteristic as that lining the uterine cavity

palpation (Fig 25) The involvement of the sigmoid may be superficial, as shown in Figures 26 and 32, and already discussed When the invasion is deep, it may cause an indentation of the wall of the sigmoid, with or without characteristic gross lesions on the surface (Figs 4, 27 and 41) The condition may sometimes closely simulate carcinoma The implantation may involve the epiploic appendages, they may become thickened and contracted, sometimes "curled up" (Figs 4 and 6) Two epiploic appendages may become adherent to each other, as though tied together (Figs 37 and 39) The epiploic

appendages may furnish a portal of entry to the invasion of the sigmoid, as suggested in Figures 42 and 46. The vermiform appendix may be invaded from implantations on its surface (Figs 47 and 48), its mesentery (Figs 20 and 21) and at the junction of its mesentery with the appendix (Figs 50 and 56).

Two instances of invasion of the small intestine are reported in this series, one from implantation on the peritoneal surface, fusing the adjacent walls of the loop and invading it (Figs 53 and 54).



Fig 25 (Case 10)—Condition prior to the operation, as seen in sagittal section of the uterus and adjacent structures,  $\times \frac{2}{3}$ . The implantation adenoma lodging and growing in the culdesac has invaded both the uterus and the rectum, fusing these parts, and has extended downward between the rectum and the vagina to the right of the cervix (the perforated hematoma was in the right ovary) forming a tumor which could be distinctly felt before operation both on vaginal and rectal palpation.

The second was by direct extension from an implantation on the surface of the uterus, which became adherent to a loop of the small intestine and superficially invaded the intestine but more extensively invaded the uterus, forming an "adenomyoma" (Figs 59 and 60).

Of great pathologic and clinical importance is the invasion of the lymph channels by endometrial polyps (Figs 44 and 45) The latter suggests that metastases may arise and explains the origin of adenoma of endometrial type found in the groin and other places, just as metastases in such places occur in ovarian carcinoma Such metastases may also arise from "adenomyoma" arising from the mucosa of the uterine cavity or the fallopian tube In a case which I am studying at the present time, an "adenomyoma" was present in both the groin and the uterus



Fig 26 (Case 8)—Implantation adenoma (of endometrial type) of the sigmoid, anterior and posterior surface of the uterus, large hematoma of endometrial type of the left ovary with evidence of a previous perforation, uterus retroverted, its posterior wall being adherent to the rectum and sigmoid View of the pelvic contents from above,  $\times \frac{3}{4}$  The hemorrhagic bleb (*a*) on the mesentery of the sigmoid is similar to the one shown in Figure 4 and also to the ones indicated by the letters *c* and *d* of this illustration An adenoma of endometrial type was present in the uterine wall beneath the blebs (*c* and *d*), and I believe the blebs were encysted menstrual blood from the adenoma implanted in these areas The area on the sigmoid indicated by *b* was slightly elevated and contained small pigmented elevations, the latter probably due to retained blood in dilated tubules of endometrial type or hemorrhage into the tissues about these tubules as shown in Figure 22 The areas at *a* and *b* were not excised

For further details in regard to the pathologic conditions arising from these implantations on the intestines, see the illustrations with their legends

#### CLINICAL FEATURES OF INTESTINAL ADENOMAS OF ENDOMETRIAL TYPE

These adenomas are analogous to the intestinal carcinomas resulting from the implantation of malignant epithelium directly on the surface of the intestine or the invasion of the intestine from an implantation on an adjacent structure. In ovarian carcinoma, with its secondary peritoneal implantations, the conditions resulting from these implantations may be of much greater pathologic interest and



Fig 27 (Case 8)—Implantation adenoma of the sigmoid (natural size) This was situated just back of the fundus of the uterus. The intestine is indented at this place (*ad*), its wall is thickened, and small pigmented pockets and slight elevations are present as in Figure 26 *b*. This area was not excised.

clinical importance than the primary growth in the ovary or ovaries, which is sometimes small. The first definite symptom arising from an ovarian carcinoma with its secondary implantations may be that of intestinal obstruction due to the occlusion of the lumen of the intestine invaded by the implantation. In other instances of peritoneal carcinoma, the involvement of the intestines is chiefly of histologic interest as compared with the primary growth. This is also true of ectopic pelvic adenomas of endometrial type. Fortunately, the latter are not so invasive as carcinoma, they grow more slowly, and their distribution is more limited. They differ from carcinoma in another interesting

feature. They may combine function with invasions, they may take part in menstruation. The escape of the menstrual blood from the implantation into the peritoneal cavity may cause other implantations and may give rise to pain during the menstrual period. The distention of hematomas with menstrual blood may also cause pain at that time, and if the hematomas are situated in the wall of the intestine, the impairment of its function may be more evident or only present during menstruation (Cases 2, 4, 8 and 10).

All implantation pelvic adenomas of endometrial type have certain clinical features in common. They usually manifest themselves in



Fig 28 (Case 8) —Perforated hematoma (of endometrial type) of the left ovary with implantation adenoma of the posterior uterine wall. Posterior view of the uterus, tubes and ovaries,  $\times \frac{3}{4}$ . The uterus was densely adherent to the rectum and sigmoid and was separated from the latter with difficulty. When an attempt was made to free the left ovary, the wall of its hematoma was torn and a large amount of "chocolate" fluid escaped. The wall of the hematoma was so densely adherent to the sides of the pelvis that it was removed in fragments, hence the hematoma is indicated only in outline. Both tubes were apparently patent, and the left tube was covered with adhesions, probably due to the irritating action of the contents of the hematoma. Sections of the left tube showed, in places, implantation adenoma. The hemorrhagic blebs on the fundus at *a* are the same ones shown in Figure 26 *b*. The pitted appearance of the posterior wall of the uterus indicated by *b* is characteristic of implantation adenoma when involved adherent structures have been separated thus exposing the adenoma in the depressions or pits between the adhesions (Compare Figs 29 and 30).



women between 30 years of age and the menopause. They may occur in younger women but I have seen only one instance in a woman after the menopause. In this case the condition was apparently inactive. There is often a history of sterility in married women or of no pregnancies in several years. The latter condition may in part be due



Fig 29 (Case 8) —Implantation adenoma invading the wall of the uterus. Photomicrograph of a portion of the uterine wall through one of the pits. The arrow indicates the bottom of the pit between the adhesions. The adenoma on the surface of the uterus is here shown invading the wall of the uterus.

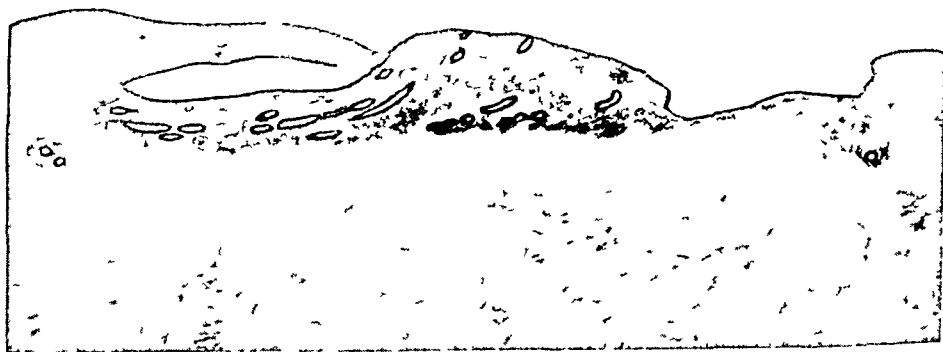


Fig 30 (Case 8) —Implantation adenoma on the surface of the uterus. The photomicrograph shows a polypoid condition of the endometrium lining the bottom of a wide pit which has been exposed by freeing the uterus from the adherent sigmoid.

to the age of the patient, as these adenomas frequently occur in women in the latter part of the child-bearing age. Painful menstruation of the acquired variety, or increasing in severity, is quite a common symptom (Cases 2, 4, 5, 8 and 10). If pain is present, independent of menstruation, it is not characteristic but varies as does pain associated with pelvic adhesions due to other conditions. The symptoms for which the patient seeks relief may be due to some other

pelvic condition and the adenomas may be an accidental finding (Cases 1, 3, 5, 6 and 7) The implantation on, or the invasion of, the intestinal tract may be chiefly of histologic interest (Figs 20, 32, 37, 47, 50 and 56) and does not cause any symptoms When the growth in any way encroaches upon the lumen of the intestine, then symptoms

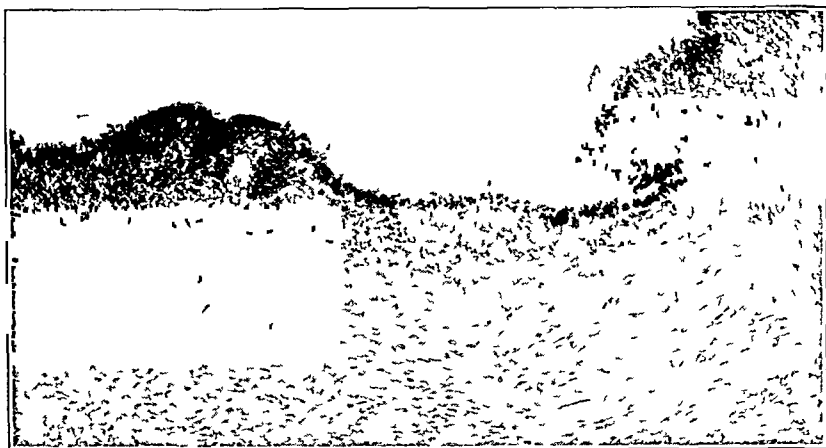


Fig 31 (Case 8)—Photomicrograph showing the lining of the ovarian hematoma near the hilum of the ovary Epithelium of endometrial type is still present in places, in other places it has been carried away by the underlying hemorrhage escaping into the cavity of the hematoma The greater portion of the hematoma was lined by a pigmented layer of ovarian stroma (evidence of old hemorrhage), without an epithelial covering Epithelium escaping through the perforation could have given rise to the implantations

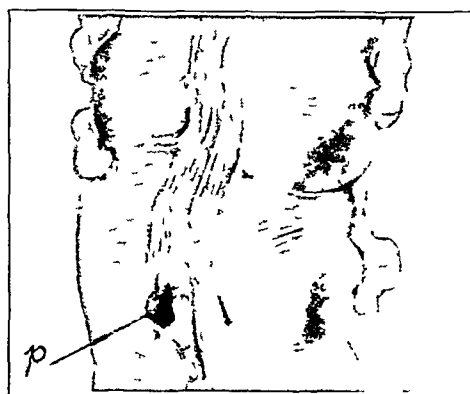


Fig 32 (Case 11)—Uterine polyp *p* attached to the peritoneal surface of the sigmoid (natural size) Implantation adenoma of endometrial type (Compare Fig 33)

arising from this may occur, and these may be more marked or only present, during the menstrual period (Cases 2, 4, 8 and 10 Figs 4, 25, 27 and 42) Marked constipation, partial obstruction painful

bowel movements and pressure sensations in the rectum during the menstrual period, especially in women between 30 years of age and the menopause, are suggestive of this condition

The physical signs vary greatly. The involvement of the intestine may be so slight or the lesion may be so situated that it cannot be detected prior to operation. The palpatory findings in the culdesac, when present, furnish the most characteristic physical signs. The uterus is often retroflexed or retroverted and adherent. It often contains leiomyomas. The palpatory findings of an adenoma which may be detected on digital palpation through the vagina or rectum depend on many factors, as its situation, extent and form. It may be localized

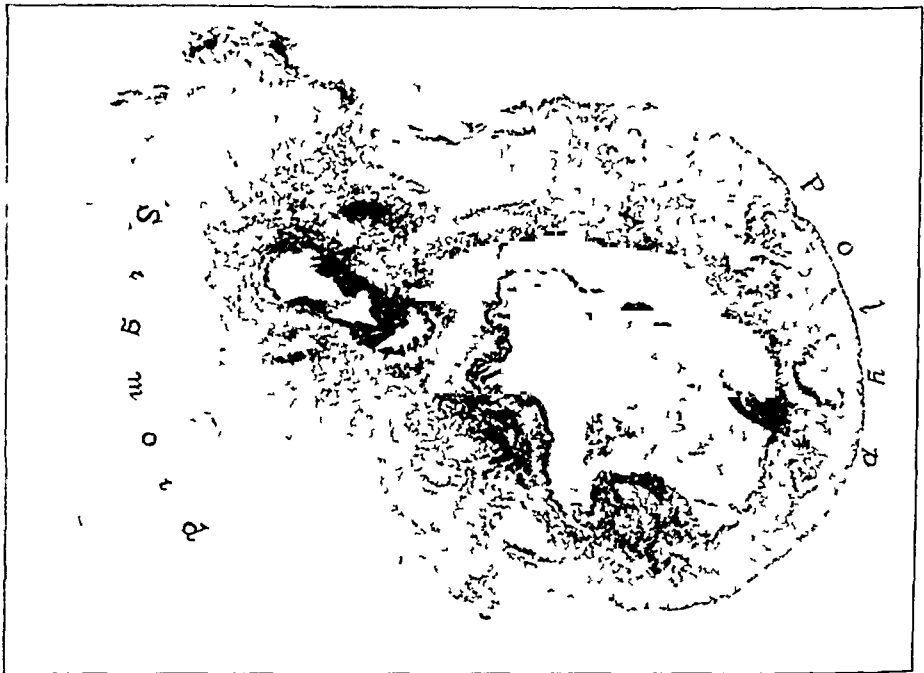


Fig 33 (Case 11) —Photomicrograph of a longitudinal section of the polyp shown in Figure 32. Histologically, it is similar to a polyp arising in the uterine cavity. Where could it have come from? Compare Figures 35 and 36

or diffuse, slight or extensive, smooth or nodular (shotted). If slight, the rectal involvement gives the impression of a slight thickening in the anterior rectal wall or a localized nodule without involvement of the rectal mucosa. In extensive cases it may simulate malignancy. Sometimes a condition which gives the impression of involvement of the anterior rectal wall proves at operation to be an invasion of the posterior wall of the cervix or uterus which is adherent to the rectum. In other cases the adenoma may extend down between the rectum and vagina forming a tumor in this situation (Fig 25).

The ovarian hematoma, if large, may be readily detected and the condition may simulate an adherent or malignant ovarian cyst (Figs .

3 and 26) If smaller it may simulate, on palpation, adherent ovaries associated with the results of pelvic peritonitis. In other instances, the ovarian condition may be so insignificant that it cannot be detected prior to operation, it may also be easily overlooked at the time of the operation and even in the routine examination of the ovaries in the pathologic laboratory (Figs 51 and 52). There is also the possibility that implantation adenoma of endometrial type may arise from other sources than ovarian hematomas, as will be discussed later.

The diagnosis of this condition prior to operation can usually be made in typical cases. The age of the patient, the acquired dysmenorrhea, the disturbance of intestinal function during menstruation, the



Fig 34 (Case 11) —Photomicrograph of an implantation adenoma of endometrial type on the posterior surface of the uterus (Fig 35 *a*). Histologically, it is endometrial tissue, similar implantations were also found on the anterior surface of the uterus. Where could they have come from? Compare Figures 35 and 36.

detection of a small adherent ovarian cyst or adherent ovary and the palpatory findings in the culdesac present a syndrome rarely furnished by any other condition. In a typical case or in those dominated by some other and a more evident, condition, the pelvic adenoma is easily overlooked. Of the nineteen cases of ectopic pelvic adenomas in which I have operated since May 1, 1921, a correct preoperative diagnosis of the condition was made in ten and it should have been made in three others. In the remaining six the diagnosis could not have been made prior to operation as the adenomas were small and insignificant. Of the ten cases in the present series in which I operated a correct preoperative diagnosis of the condition was made in five and should have been made in two others.

## TREATMENT

The operative treatment of any pelvic condition occurring in women who are still in the child-bearing age should be determined by many factors, such as the pathologic condition, the desire of the patient for conservative surgery, the results of the operative treatment of similar conditions and especially the natural course of the disease without operative interference. There are usually two pathologic conditions which present themselves at the time of the operation in implantation adenomas of endometrial type, first, the hematoma of the ovary or ovaries which may be the most evident pathologic condition found



Fig 35 (Case 11) —Perforated hematoma (of endometrial type) of the left ovary with implantation adenomas (of endometrial type) on the anterior and posterior surfaces (Fig 34) of the uterus and on the anterior surface of the sigmoid (Figs 32 and 33). Posterior view of the uterus, tubes and ovaries,  $\times \frac{2}{3}$ . When the adherent left ovary was freed a small amount of "chocolate" fluid escaped because a previous perforation (*p*) of the hematoma, which had been sealed by the side of the pelvis to which the ovary had become adherent, was reopened. Could the implantations of adenoma have come from this source? Compare Figure 36

in the pelvis (Figs 3 and 26). In other cases the ovarian condition may be of minor importance as compared with the implantation adenomas or is so insignificant as to be overlooked easily or it may occasionally be absent. Second, the implantation adenoma of some portion of the intestinal tract may be the outstanding condition (Fig 41). In other cases it may be insignificant (Figs 32 and 37). One

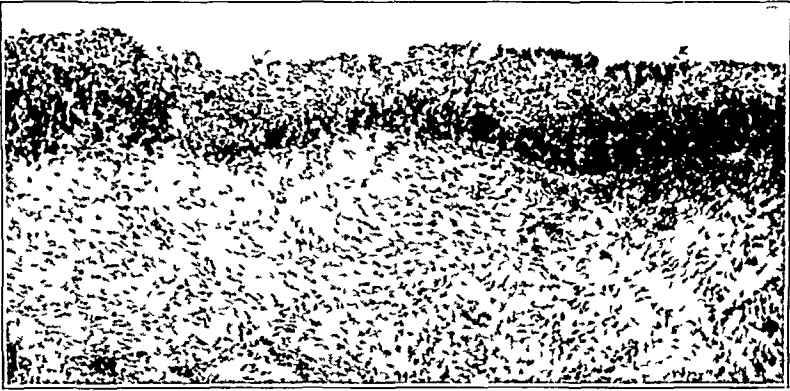


Fig 36 (Case 11) —Photomicrograph of a section of the wall of the ovarian hematoma. It is in part lined by epithelium of endometrial type. Its function is similar to that of endometrium, namely, menstruation. Evidence of recent (fresh blood) and old hemorrhage (pigmented cells) is present in the wall of the hematoma, thus suggesting repeated hemorrhage as in menstruation. Some of the epithelium has been carried away by the underlying hemorrhage. What became of this epithelium? The evidence of a previous perforation would indicate that some of it might have escaped into the peritoneal cavity with the contents of the hematoma at the time of the perforation. The implantation adenomas just described have developed where the contents from such a perforation would be likely to fall.

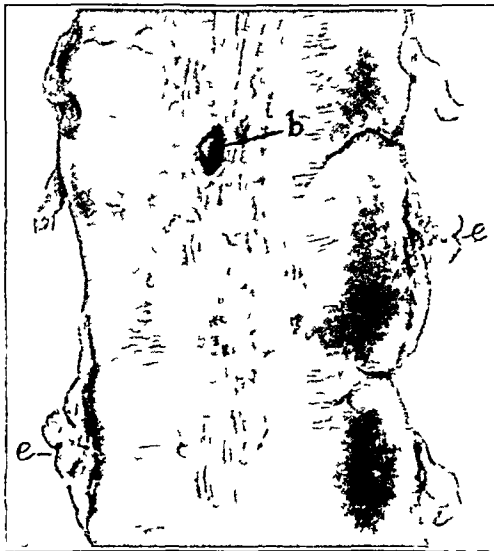


Fig 37 (Case 7) —Implantation adenoma (of endometrial type) of the sigmoid and its epiploic appendages (natural size). Many irregular white elevations were present on the anterior surface of the sigmoid, apparently scars resulting from some irritating substance coming in contact with it. A brownish pigmented bleb is present at *b* (Compare Fig 38) and two epiploic appendages on each side of the sigmoid (*c*) are adherent to each other as though ligated. The bleb (*b*) was excised and the epiploic appendages (*c* and *c*) were removed (Fig 39).

would suppose that with the establishment of the menopause ovarian function would cease and that the implantation adenomas of endometrial type wherever situated would not only stop growing but would actually atrophy. I believe this is the rule, possibly there may be an

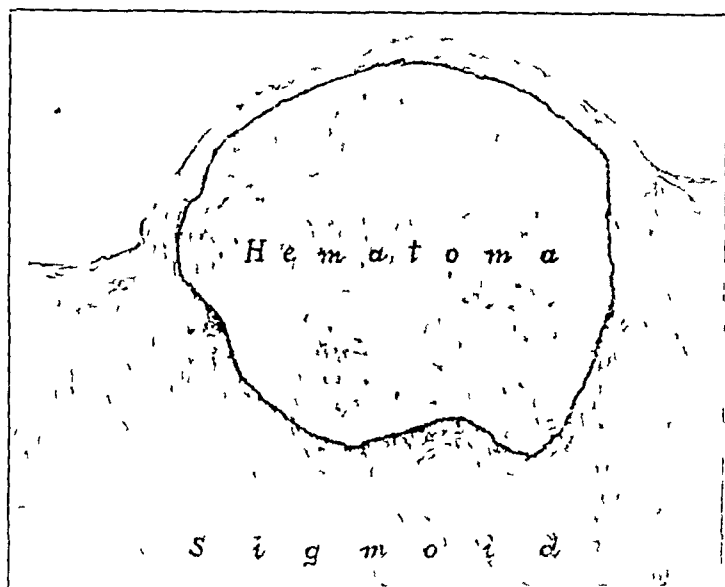


Fig 38 (Case 7)—Cross-section of the bleb *b* (Fig 37). It is a hematoma filled with old blood and lined by epithelium, columnar near the base and flattened toward the periphery. I believe it is a hematoma of endometrial type. Where could it have come from? Compare Figure 40.

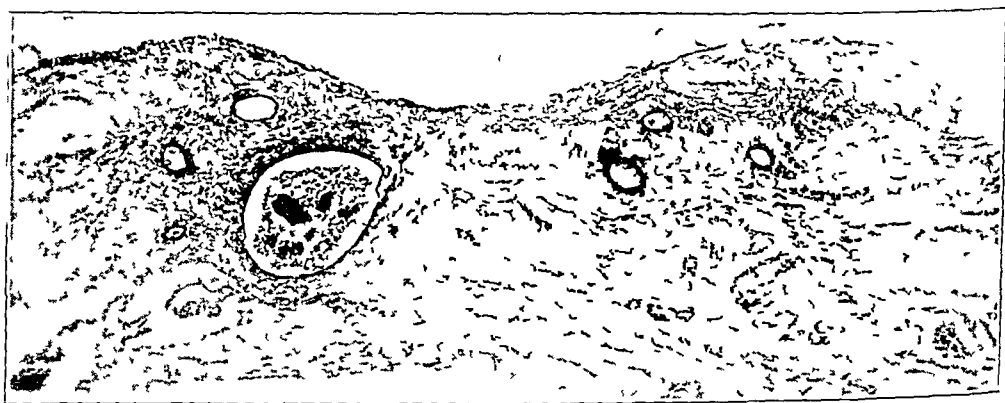


Fig 39 (Case 7)—Cross-section of two of the fused epiploic appendages. They have become fused and are invaded by tubules of endometrial type.

occasional exception. To attempt to remove the pelvic implantation adenomas and disregard the condition in the ovaries or to preserve ovarian tissue is attended with the danger of possibly leaving an important focus in the ovaries for reimplantation, and, furthermore,

the persistence of ovarian function may stimulate the growth of implantations, which were not removed, wherever they may be situated (Case 12) My present reaction in these cases is to remove the uterus, both tubes and ovaries, and to disregard the implantations (including intestinal), except as they may be easily removed for histologic study (Cases 4, 7, 8, 10 and 11) The uterus is often retroflexed and adherent, and myomas and other pathologic conditions are present, as shown in the cases reported in this and in the previous series There are, therefore, often indications for the removal of the uterus, tubes and ovaries other than the implantations and ovarian hematomas I have occasionally saved ovarian tissue in these cases,

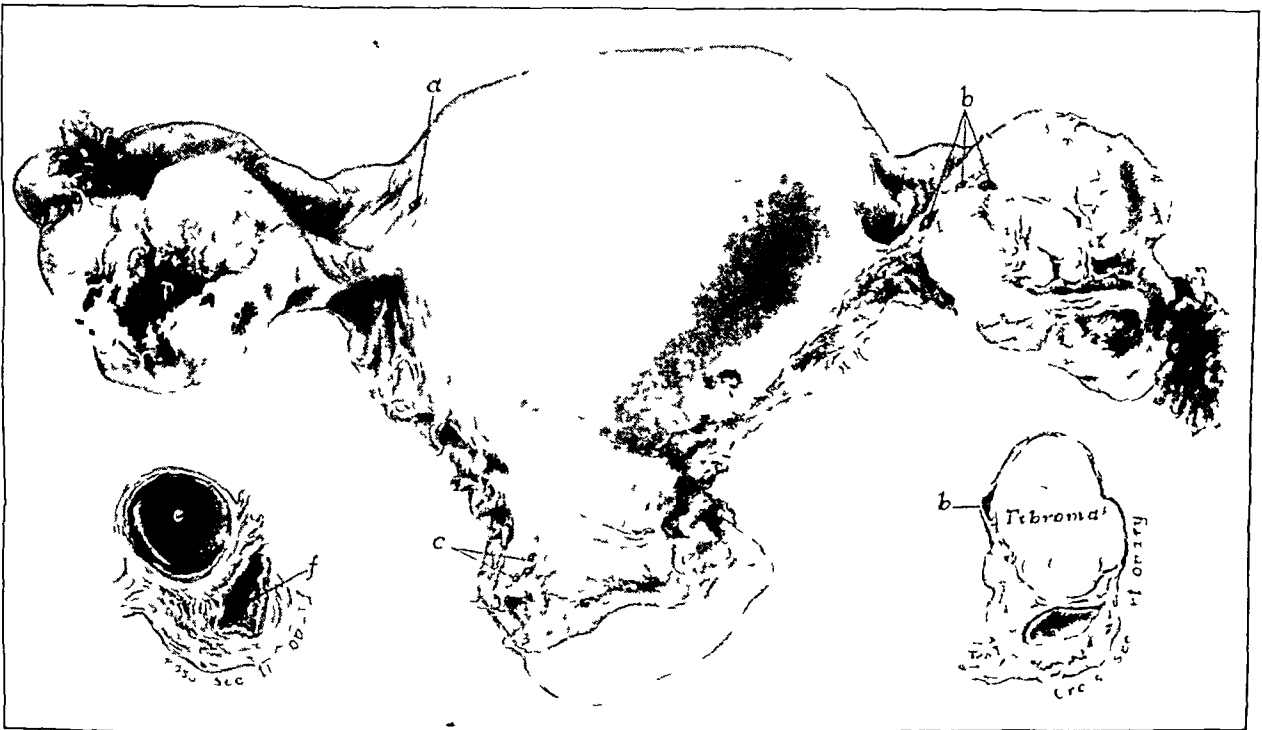


Fig 40 (Case 7) —Perforated hematoma (of endometrial type) of the left ovary with implantation adenoma on the posterior surface of the uterus (*a* and *c*) and the right ovary (*b*), fibroma of the right ovary, submucous leiomyoma of the uterus. Posterior view of the uterus and tubes, ovaries turned upward, showing their under and lateral surfaces,  $\times \frac{2}{3}$ . On freeing the adherent left ovary a small amount of "chocolate" fluid escaped from a previous perforation (*p*), which was reopened. The ovary, which is shown in cross-section contained two hematomas of endometrial type, one (*e*) had not perforated and the other (*f*) had. Implantation adenomas of endometrial type are present at *a*, *b* and *c*. The right ovary, which is shown in cross-section, contained a fibroma. The lining of the perforated hematoma of the left ovary is similar to the one shown in Figure 36. The left ovarian hematoma of endometrial type with evidence of a previous perforation indicates a source of the implantation adenomas.



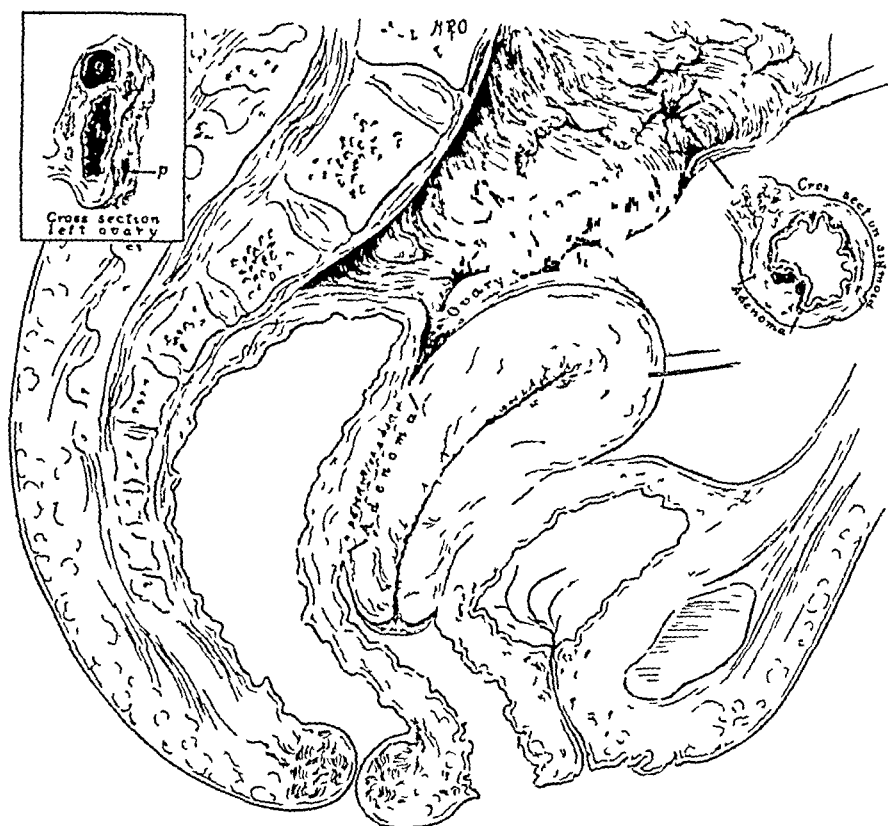


Fig 41 (Case 2)—Implantation adenoma (of endometrial type) of the sigmoid, uterus, rectum, ovaries and perforated hematoma of endometrial type of the left ovary, small leiomyomas of the uterus. Sagittal section of the pelvis ( $\times \frac{1}{2}$ ), showing the condition found at operation. On drawing the uterus upward and forward the rectum and lower sigmoid were carried with it because they were fused with the posterior wall of the cervix and uterus. Indentations of the sigmoid were situated at *A* and *B*. The one situated at *A* was the more evident of the two, the wall of the sigmoid about the indentation was thickened, and on palpation it simulated carcinoma. On freeing the left ovary an ovarian hematoma (*h*) was ruptured (*p*), compare cross-section of the left ovary in the insert. This proved to be a hematoma of endometrial type fully described in Case 19 of the previous publication. The indurated area *A* of the sigmoid was excised and a section of this area is shown in the insert and in Figure 42. Implantation adenoma was also found invading the posterior uterine wall, the left broad ligament (Fig 45) and the surface of both ovaries. What is the source of these implantations? The ovarian hematoma of endometrial type of the left ovary with evidence of a previous perforation could have furnished the epithelium from which these implantations arose, just as ovarian cancer with evidence of a perforation gives rise to peritoneal implantations.

as in Cases 1 and 5 of this series and in some of those reported in the previous series and intended to do so in selected cases. Three of the patients whose cases were reported in the previous series were not relieved by the operation and one was operated on again<sup>1</sup>. I am awaiting with great interest the end-results of all of these cases.

We must not lose sight of the fact that for many years we have been operating in these cases without realizing the exact nature of the disease. The results have been for the most part quite satisfactory,



Fig. 42 (Case 2)—Section of the wall of the sigmoid which was excised (Fig. 41 A). It shows a typical adenoma of endometrial type. The implantation apparently began on the peritoneal surface, possibly through an epiploic appendage, indicated by the arrow, and invaded the subserosa and then wormed its way through the muscularis forming hematomas (H) in the submucosa. The latter were filled with retained "menstrual blood." The hematoma on the left is in part lined by typical uterine mucosa. The patient complained of dysmenorrhea and symptoms of intestinal obstruction at the menstrual period. The distention of the hematomas with blood at the menstrual period offers an explanation of the cause of the intestinal obstruction at that time.



Fig 43 (Case 2) —A small uterine cavity found in a section of the wall of the sigmoid



Fig 44 (Case 2) —Endometrial polyp invading a lymph vessel in the subserosa of the sigmoid. These polyps are frequently found in implantation adenomas of endometrial type

because the growth is usually of only histologic interest or only mildly invasive, and often the proper operative treatment was used without realizing it. I wish to emphasize what seems to me to be an important practical point. On detecting what appears to be a carcinoma of some portion of the intestines, especially of the sigmoid and rectosigmoid, the surface of this area should be carefully inspected to see whether it presents the external features of an implantation adenoma of this type (Figs 4, 14, 19, 27, 32 and 37), other implantations should be looked for, and, most important of all, the ovaries should be carefully examined to see whether a hematoma is present with evidence



Fig 45 (Case 2)—Implantation adenoma (*a*) on the surface of the broad ligament and invading a lymph vessel in the broad ligament. Two endometrial polyps (*e, p*) are shown, the larger one came from the adenoma (*b*) of this illustration. The invasion of the lymph vessels by these adenomas suggests that they may metastasize through these channels and offers one explanation for the appearance of adenoma in the groin. The invasion of the uterine wall was described in the previous article.

of a previous perforation, bearing in mind that the ovarian hematoma may be small (Fig 52). If these are found, the true diagnosis is evident. My present opinion is that on making such a diagnosis it is preferable not to resect the portion of the intestine involved but to deal with the pelvic organs as I have just stated.

#### THE ORIGIN AND DEVELOPMENT OF OVARIAN HEMATOMAS OF ENDOMETRIAL TYPE

In the previous communication I<sup>1</sup> described small hemorrhagic areas in the ovaries of three patients that had been operated on

during their menstrual period. Histologically, these areas proved to be due to hemorrhage about, or into, a space lined by tissue of endometrial type. I stated that I believed that these glandlike spaces were lined by epithelium of endometrial type, as shown by their structure and by their function (menstruation). I also stated that ovarian hematomas of endometrial type might arise from this misplaced epithelium either



Fig 46 (Case 1) —Section of the wall of the sigmoid showing an adenoma of endometrial type invading it. A portion of the sigmoid was resected (diagnosis of carcinoma). The left ovary was cystic and adherent. The left tube and ovary were removed. There was no note in the record of the case in regard to the exact condition of the ovary (operation twelve years ago). The portal of entry of the implantation was apparently on the surface of the intestine near the place indicated by the arrow. The adenoma first invaded the subserosa and then wormed its way through the muscularis forming a hematoma at H. The section suggests that the portal of entry might have been through an epiploic appendage. Many of the epithelial cells in the dilated tubules were ciliated.

by reining a follicular hematoma which might rupture near, or into them (the secondary epithelialization of follicular hematomas), or by hemorrhage (menstrual) into the lumen of the gland or space, they may develop into endometrial hematomas which they already are in miniature (Fig 62). I have been unable to demonstrate the secondary epithelialization of follicular hematomas. Many sections which I have

seen might be interpreted as such, but all of these can be better explained by the regeneration of an endometrial hematoma, after hemorrhage and perforation, from epithelium left behind or possibly from cells which escaped through the perforation but which have grown in again. I have found every stage in the development of ovarian hematomas of endometrial type from these glands and tubules lined by tissue of endometrial type which may react to the menstrual impulse. If these tubules or glands are situated near the surface of the ovary, perforation occurs while they are still small (Fig 62), a few millimeters in diameter or even microscopic in size. Epithelium may escape into the peritoneal cavity from these miniature hematomas (perforating hemorrhagic cysts) and give rise to implantations. Repeated hemor-

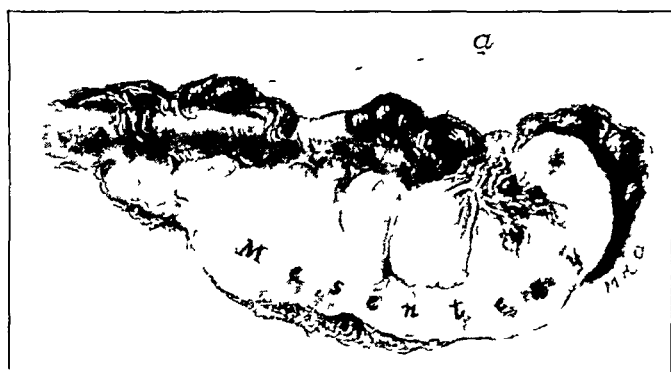


Fig 47 (Case 9)—Implantation adenoma (of endometrial type) on the appendix and its mesentery, invading the former at *ad*, Figure 48. The appendix, uterus and both tubes and ovaries were removed (operation by Dr Elting). The dark elevations on the surface of the appendix and its mesentery consist of typical endometrial tissue with hemorrhage in its stroma (Fig 49). Adenoma of endometrial type was also found invading the posterior wall of the uterus. What is the source of these implantation adenomas of endometrial type? Typical hematomas of endometrial type were present in both ovaries with evidence of perforation.

rhages into the lumen of the smaller cysts, with loss of the overlying epithelium and repeated perforations, may destroy the cyst. If the endometrial tubule is situated in the deeper portion of the ovary, then it may develop into a large hematoma before perforation as in Figures 13, 18, 19 and 28. In the previous communication I referred to the pigmented "luteal" lining in parts of some of the hematomas which differed from that of a corpus luteum hematoma. At that time I believed that this "luteal" like lining in many of the specimens arose from hemorrhage into the wall of an endometrial cyst with subsequent loss of the overlying epithelium and the retention of the blood pigment in the tissues and cells of the cyst wall and this is true. There were other instances in which this pigmented layer resembled the remains of a

corpus luteum and I was uncertain as to its origin in these cases. The endothelial leukocytes, which often play an important rôle in the development of the pigmented "luteal" layer, may sometimes simulate in their appearance and arrangement true luteal cells. My later studies have shown me that the development of all of the luteal-like layers in all the sections which I have studied of this type of ovarian hematoma



Fig 48 (Case 9) —Implantation adenoma (of endometrial type) on the surface of the appendix and invading its wall at *ad*. Cross-section of the appendix and its mesentery taken through one of the hemorrhagic elevations shown in Figure 47

may be traced from hemorrhage into the ovarian tissue lining the hematomas and its invasion by endothelial leukocytes. The various changes which take place in these hematomas during their development (including their reaction to menstruation) and retrogression must be reserved for another communication.

How does the epithelium of endometrial type reach the ovary? Is it of müllerian or wolffian duct origin? Cilia are sometimes present on



Fig. 50 (Case 6) —Photomicrograph of a portion of the wall of the appendix and its mesentery showing tubules of endometrial type (a). Some of the cells were cubited. Small implantations of endometrial type were also present in the culdesac. Where could they have come from? Compare Figure 51



Fig. 50 (Case 6) —Photomicrograph of a portion of the wall of the appendix and its mesentery showing tubules of endometrial type (a). Some of the cells were cubited. Small implantations of endometrial type were also present in the culdesac. Where could they have come from? Compare Figure 51



the epithelium lining these tubules in the ovary, likewise on the epithelium in the larger hematomas and in the implantation adenomas. Cilia may sometimes be found on the epithelium of the uterine mucosa, more often on that lining the fallopian tubes and at times in the "adenomyomas" arising from the invasion of the uterine and tubal mucosa into the walls of the uterus and tube. The most natural conception of their origin would be that they arise from developmentally misplaced müllerian epithelium (Russell) or from the invasion of

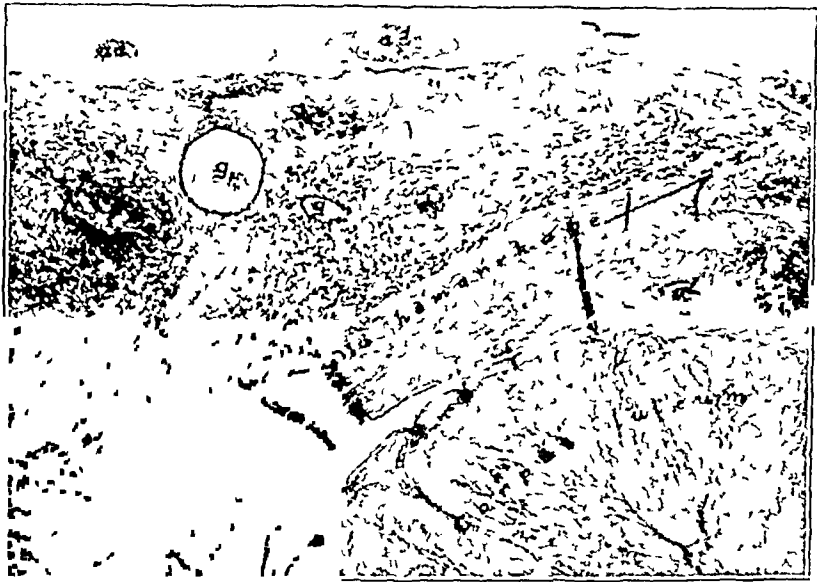


Fig 51 (Case 6) —Photomicrograph through a small pigmented area on the lateral surface of the right ovary showing tubules of endometrial type (*g*) similar to those found in the appendix (some of the cells were ciliated). The right ovary was lightly adherent (compare adhesions *ad*) in the photomicrograph. Two small areas of pigmentation were noticed on the lateral and lower surfaces of the ovary. The pigmentation was due to the remains of a former stromal hemorrhage. The condition may be the remains of a small ovarian hematoma of endometrial type, as in Figure 52. Repeated hemorrhages and perforation with the casting off of the epithelium lining the hematoma may have removed the greater portion of this epithelium and the present condition arose from the repair which followed. A few epithelial cells remained and these developed into tubules or glands (*g*). Some of the epithelium which was cast off could have given rise to the implantations in the appendix and in the culdesac.

tubal epithelium from the fimbriae in contact with the ovary. Tubules are sometimes present in the hilum of the ovary which are apparently of wolffian duct origin and these might be considered as a source of these hematomas.

The data which I have been able to obtain suggest that tubal and uterine epithelial cells may, under certain circumstances (as an abnormal menstruation with a backflow), be expelled from the

fimbriated end of the tube and lodge on the surface of the ovary. They may become embedded in the tissues of the ovary and, true to their type, form glands and tubules which may actually invade the ovary. The process is analogous to that which results from the implantation of epithelial cells on the peritoneum from the perforation of ovarian hematomas of endometrial type, as described in the previous and also in this communication. Some of these glands and tubules which have invaded the ovary react to menstruation and develop into hematomas of endometrial type (Fig 62). If they are situated near the surface of the ovary, perforation occurs early (while the hematoma is small,



Fig 52 (Case not reported in this series) —Photomicrograph of a small perforated hematoma of endometrial type of the ovary. This hematoma was about 15 mm in diameter. It is lined by epithelium of endometrial type, some of which is ciliated; underlying stromal hemorrhage (menstrual) is present. Some of the epithelium has been cast off by this hemorrhage, rupturing into the lumen of the hematoma. A perforation of the hematoma is present, and implantation adenomas were also found in the culdesac, invading the posterior wall of the uterus. Repeated hemorrhages and resulting loss of the epithelial lining of the hematoma followed by repair might give rise to the condition shown in Figure 51. If all of the epithelium was destroyed it might in time be impossible to find any trace of the hematoma in the ovary, and I believe that this sometimes occurs.

Fig 52) and some of the epithelium lining the hematoma, which has been expelled into the cavity of the latter by the subepithelial hemorrhage of menstruation, may be carried with the hemorrhagic contents of the hematoma through the perforation into the peritoneal cavity. Implantation adenoma of endometrial type may arise from the contents of such a hematoma as well as from the larger ones, but they are apparently not so widely distributed. If the hematoma develops from a tubule which has penetrated the deeper tissues of the ovary, it may reach a larger size before perforation occurs and a larger amount of menstrual blood, including epithelium, may escape into the

pelvis than from a smaller hematoma. Implantation adenoma from a perforated ovarian hematoma may arise on any of the pelvic structures, including the surface of the ovary from which the perforation has occurred, and also on the opposite ovary and develop into other ovarian hematomas. I consider the ovary as a sort of intermediary host, hotbed or incubator. A very interesting phenomenon is evident in many of these cases, that is, the epithelium expelled from these hematomas often displays a greater degree of vigor and invasiveness than similar epithelium manifests in the ovaries with hematomas which have not perforated. I also believe that it is possible that tubal and uterine epithelium escaping from the tube may become deposited on the surface of other pelvic structures than the ovary and may give rise to implantation adenomas similar to those from a perforated

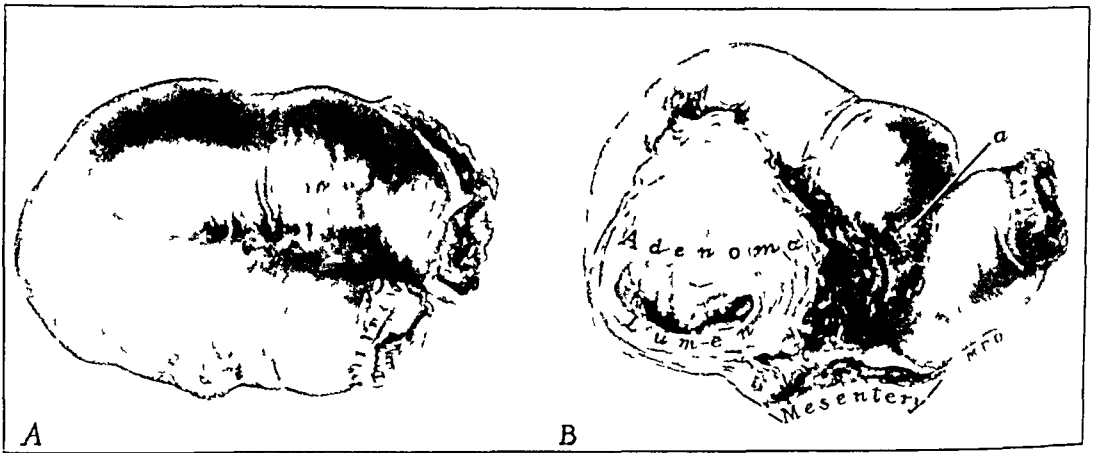


Fig 53 (Case 3) —Implantation adenoma (of endometrial type) of the ileum. About 4 inches (10 cm) from the cecum a loop of the ileum was found to be thickened and the adjacent walls of the intestine were fused together. This portion of the ileum was resected and an end-to-end anastomosis was performed (operation by Dr Sadlier). Figure A represents the appearance of the loop. Figure B shows the appearance of one half of the loop after cutting across the intestine and separating the adherent walls. The adenoma had developed on the surface of the intestine and had invaded the adjacent walls which in places were greatly hypertrophied, thus narrowing the lumen of the intestine, also shown in Figure 54, a section from another portion. The elevation at *a* is a growth (implantation), histologically similar to a uterine polyp.

ovarian hematoma. In the cases which I have interpreted as possibly arising in this manner, the implantations have not shown the same degree of vigor and invasiveness as those usually found when an ovarian hematoma with evidence of a previous perforation is present, and histologically they may differ in minor ways. It is for these reasons that I look upon the ovary as an intermediary host, a hotbed or incubator. In the cases above referred to, the implantations may have come from a small ovarian hematoma which has disappeared.

This theory as to the origin of these ovarian hematomas and also their relation to endometrial implantations is based on the following data. The ovarian hematomas are of endometrial type as shown by their structure, function (reaction to menstruation) and their endometrial implantations. They are rarely found in women under 30 years of age. If of developmental origin, we would expect to find them in younger women. They develop during the menstrual life of the patient in a period when tubal and uterine epithelium might escape from the fimbriated end of the tube and become deposited on the

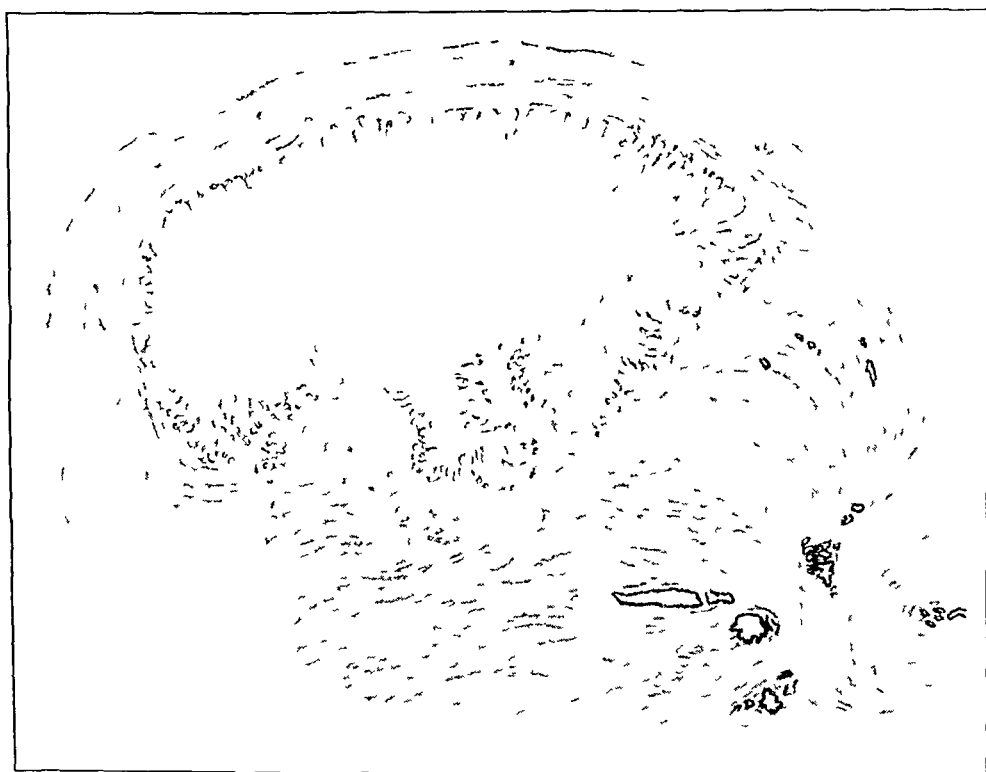


Fig 54 (Case 3)—Adenoma (of endometrial type) invading the ileum. Cross-section of the intestine showing the adenoma invading its wall and the marked thickening of the circular muscle. What is the source of the adenoma? Compare Figure 57.

surface of the ovary just as peritoneal implantations arise from the perforation of ovarian hematomas. In forty-nine cases of perforated ovarian hematomas which I have studied, the tubes were apparently patent in all, suggesting that this avenue for this source of implantation was open. These hematomas usually develop on the lateral and the under surfaces of the ovary, the portions of the ovary most likely to be soiled by material escaping from the lumen of the tube, as well seen in the ovarian adhesions found in pelvic inflammatory disease of gonorrheal origin, and they are also often bilateral.

In thirty-seven cases of ovarian hematomas of endometrial type with perforation, in which I have studied microscopically the tissues involved in the adhesion apparently resulting from escape of the contents of the cyst, adenoma of endometrial type was found in all but one specimen. On the other hand, in three cases of typical ovarian hematomas of endometrial type without any evidence of perforation, adhesions were not present in the pelvis and there was not any gross evidence of implantation adenomas, the pelvis was examined very carefully in each instance. In the cases of perforated ovarian hematoma with implantation, the extent of the implantation usually varied with the size of the hematoma and apparent size of the perforation. The larger the hematoma and the greater the size of the perforation the more extensive the distribution of the implantations.

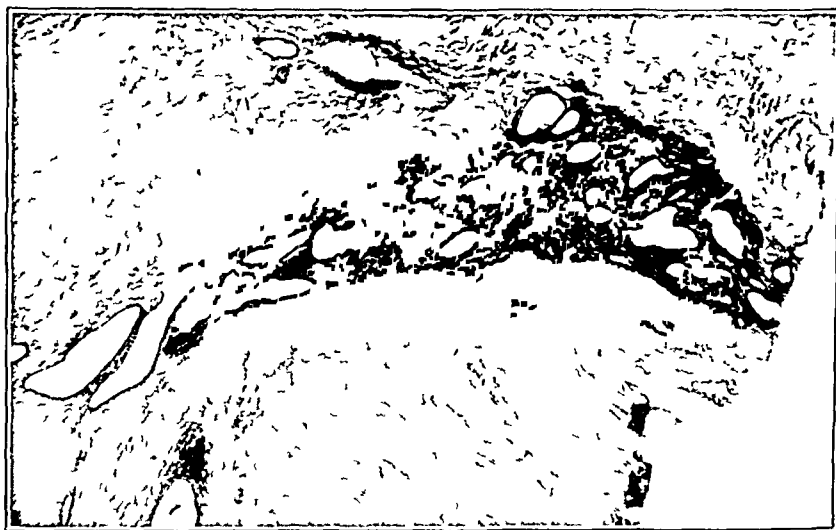


Fig 55 (Case 3) —Adenoma (of endometrial type) invading the wall of the intestine. Photomicrograph showing the adenoma pouring into the muscular coats of the intestine.

May implantation adenoma occur from other sources than a perforated ovarian hematoma of endometrial type? I believe that this is possible, although it is difficult to exclude the ovarian source in any case. The ovarian hematomas may be very small and easily missed (Fig 52), or as the result of repeated hemorrhage and loss of epithelium, they may become inconspicuous (Fig 51) or even disappear. I believe that tubal and uterine epithelium escaping from the tube into the peritoneal cavity might, under proper conditions, give rise to implantation adenomas in the culdesac or wherever the epithelium may lodge, just as I believe the ovarian hematomas arise from this source. During the last year and a half I have operated on six

patients for uterine myomas in whom small peritoneal implantations of endometrial type were found in the culdesac without gross evidence of a perforated hematoma in the ovaries. One or both ovaries were removed in each instance. In the ovaries of three of the six patients, tubules of endometrial type were found, which I interpreted as the possible remains of a small ovarian hematoma which had perforated, or they were tubules which had not developed into hematomas. In a fourth specimen, an area containing pigmented cells was found in the ovary, which suggested the remains of a small ovarian hematoma. In the other two cases, tubules of endometrial type were not found in the ovary and there was not any evidence of a previous stromal



Fig 56 (Case 3)—Adenoma (of endometrial type) invading the appendix. Photomicrograph of the appendix and its mesentery showing the adenoma (*ad*) invading the appendix at its mesenteric attachment. Cross-sections of small tubules of endometrial type are shown at *a* and *a*. (From a section lent by Dr H P Carpenter.) What is the source of the adenoma? Compare Figure 57

hemorrhage. These may have been missed, as serial sections of the ovaries were not made. In the other thirty-eight instances of pelvic adenoma of endometrial type, an ovarian hematoma or hematomas of endometrial type were present, with evidence of previous perforation which could account for the adhesion and implantations. It is interesting to note the difference in the character of the implantations where there was no gross evidence of an ovarian hematoma with perforation. They were usually small and inconspicuous as compared

with those usually found in the pelvis associated with ovarian hematomas with evidence of perforation, and histologically they usually differed from them in minor ways. I also believe that implantations from both sources may be present in some cases.

The epithelium lining these tubules in the ovary is often ciliated, in some instances resembling that of the fallopian tube, and in others that of the uterine mucosa. In one instance, the epithelium in places resembled the mucosa of the uterine cervix. These tubules might also develop into ovarian cysts and carcinoma. The carcinoma shown in Figures 1 and 2 may have arisen from this source. Some of the epithelium of the glands in this carcinoma resembled very closely uterine epithelium even to the presence of cilia.

The epithelium lining some ovarian cysts very closely resembles that of the mucosa of the uterine cervix and some of these cysts may arise from the tubules of endometrial type of the ovary. References to the literature on ovarian hematomas and ectopic growths of endometrial tissue in the pelvis may be found in the previous communication.

#### REPORT OF CASES

CASE 1—*Adenoma (of endometrial type) of the sigmoid, adherent cystic left ovary (whether or not containing a hematoma of endometrial type was not determined)*. Mrs. G. N. G., aged 36, complained of pain in the left lower abdomen and a sense of lack of support. She had had two children, the youngest, 9 years old. Menstruation was regular, moderate in amount and accompanied with pain (the duration of the dysmenorrhea was not noted in the case record). The patient was not constipated. Pelvic examination disclosed a weakened pelvic floor with cystocele and rectocele. The uterus was in normal position with what felt like an inflammatory mass occupying the position of the left tube and ovary. The preoperative diagnosis was a weakened pelvic floor and pelvic inflammatory disease of the left side.

At operation at the Albany Hospital, Feb. 10, 1909, the left ovary was found to be cystic and densely adherent. The right tube and ovary appeared to be normal. The left tube and ovary were removed. There is no note in the case records as to whether or not the cyst was torn and whether any "chocolate" fluid escaped into the pelvis. An indurated area was noticed in the wall of the sigmoid just below the pelvic brim. This was thought to be a carcinoma of the sigmoid, and about 8 cm. of the intestine was resected and repaired by an end-to-end anastomosis. A section of the intestine showed a typical adenoma of endometrial type, apparently invading the sigmoid from its peritoneal surface (Fig. 46). The cystic ovary was not examined histologically and I do not know whether or not a hematoma of endometrial type was present. The patient developed a postoperative phlebitis of the left leg, followed by symptoms of a pulmonary embolus. She eventually recovered and has remained well.

CASE 2 (Case 19 of previous series)—*Implantation adenoma (of endometrial type) of the sigmoid, posterior wall of the uterus, anterior wall of the rectum, and both broad ligaments, hematoma (of endometrial type) of both ovaries with evidence of previous perforations*. Mrs. J. W., aged 45, complained of marked constipation with attacks of partial intestinal obstruction, beginning

two years before the operation and gradually increasing in severity. She had two children, the youngest being 6 years old. Menstruation was regular, moderate and without pain until the last two years. During this time, pain had been present, increasing in severity, and the flow had been decreasing in amount. The patient was operated on the last day of the flow. It is of great interest to note that the attacks of the most marked constipation occurred with the menstrual period. These had been especially bad during the last year. The pain was so severe that the patient had to remain in bed, the abdomen became distended, and sometimes there was nausea and vomiting. Bowel movements were obtained with the greatest difficulty. No blood was ever



Fig 57 (Case 3)—The probable source of the implantation adenoma found in Figures 53 to 56. View of pelvic contents showing a common normal relation between the right ovary and the terminal portion of the ileum and the appendix. A typical hematoma (of endometrial type), about 2 cm in diameter, was found in the right ovary. The uterus is represented as drawn forward with myomas removed. The contents escaping from the perforation of the ovarian hematoma might easily fall on the appendix and terminal portion of the ileum in the culdesac and give rise to the implantation adenomas found in this case.



observed in the evacuations. The abdomen remained tender for about a week after the cessation of the flow. Pelvic examination demonstrated the uterus to be irregular, adherent and retroverted. The appendages were not palpated. No localized induration was detected in the culdesac. Roentgenograms were made following a barium enema, but no definite point of obstruction was found. The preoperative diagnosis was an adherent myomatous uterus with possibly a malignant growth of the sigmoid. The true condition was not considered.

At operation at the Albany Hospital, Feb. 17, 1921 the uterus, containing small leiomyomas, was retroverted and adherent to the rectum. A small amount of "old blood" was free in the pelvis. Both ovaries were cystic, enlarged, and adherent to the posterior surface of the uterus. On freeing the ovaries, "chocolate" fluid escaped. There were two definite, puckered areas in the sigmoid. One area was situated just above the apparent rectosigmoidal junction and the other 8 or 10 cm above this one. The upper area was not involved in, or continuous with, the adhesions uniting the uterus to the sigmoid or those between the ovaries and the uterus (Fig. 41). On palpating each of these puckered areas, a definite nodule could be distinctly felt, apparently projecting into the lumen of the sigmoid. The upper one was the larger. The correct diagnosis was now apparent. The appendix was first removed, then both tubes and ovaries and the entire uterus. The separation of the uterus from the rectum was extremely difficult for apparently the growth had invaded it and also the broad ligament on both sides. The upper and larger nodule in the sigmoid was excised and an end-to-end suture of the intestine was made. Histologically, the larger cyst of the left ovary was lined by a single layer of epithelium the cuboidal type predominating, with evidence of recent hemorrhage into the underlying stroma. Adenoma of endometrial type was found lining the smaller cyst or pocket and it was also found on the surface of the ovary between it and the uterus. The larger cyst of the right ovary was a graafian follicle cyst, but the smaller hemorrhagic cyst or pocket was lined by an adenoma of normal endometrial type, there was adenoma of endometrial type on the surface of the uterus, superficially invading its posterior wall. A similar adenoma invaded the wall of the sigmoid from its peritoneal surface and extended through the entire wall into the submucosa (Fig. 42). The patient made a satisfactory convalescence and has remained well. The end-result is awaited with great interest to determine the fate of the adenoma undoubtedly still present in the sigmoid and in the culdesac.

CASE 3 (Dr. Sadlier's case)—*Implantation adenoma (of endometrial type) of the ileum and appendix, hematoma (of endometrial type) of the right ovary, multiple leiomyomas of the uterus.* In April, 1921, Dr. Lawrence Early showed me a section from the small intestine, of which he had made a diagnosis of adenomyoma. The section had been sent to the state laboratory by Dr. H. P. Carpenter of Poughkeepsie. I asked Dr. Early to write to Dr. Carpenter and to ascertain whether one or both ovaries had been removed and if so whether or not they contained any hematomas. Dr. Carpenter sent a tube and ovary and a portion of the small intestine to Dr. Early. The ovary which had been sectioned contained a typical hematoma of endometrial type, about 2 cm in diameter. Dr. Carpenter referred me to Dr. J. E. Sadlier, who had operated on the patient, and it is through his courtesy that I am reporting this very interesting case. Dr. Carpenter kindly lent me the sections he had made from the specimen and with the help of these and the rest of the specimens, which he sent to Dr. Early, I was able to reconstruct the portion of the intestine as it probably appeared when first removed.



Fig 58 (Case 12)—Implantation adenoma (of endometrial type) invading the posterior uterine wall, the ileum which was adherent to the latter and also the uterosacral ligaments. Condition found at the operation after freeing the sigmoid and the ileum which were adherent to the uterus (natural size). The left tube and ovary had been removed four years before. The ovary contained a hemorrhagic cyst (see report of the case). The sigmoid was adherent to the rough area of the uterus marked *s*. Adenoma of endometrial type was found invading the uterus in this area. The ileum was so densely adherent to the surface of the uterus marked *1* that in freeing it a portion of the wall of the former was left attached to the uterus (Figs 59 and 60). Adenoma was found in the greatly thickened uterosacral ligaments (Fig 61). What is the origin of these implantation adenomas? The perforated hemorrhagic cyst of the ovary removed four years ago may have been of endometrial type and the condition found at the present operation may have been present at the first (not so far advanced) or the implantations may have occurred in freeing the cyst at the first operation.

Mrs E C, aged 42, complained of profuse menstruation of about two years' duration. She had been married fourteen years but had never been pregnant. Menstruation had been regular and painful. The pain had increased in severity lately and the flow had been more profuse. She did not have any pain between the menstrual periods, and although constipated she did not give a history of symptoms suggesting intestinal obstruction.

March 25, 1921, Dr Sadlier removed multiple myomas, the right tube and ovary and the appendix. He then noticed, about 4 inches (10 cm) from the cecum, a fusion of the adjacent walls of a loop of the ileum which felt hard and indurated and naturally led to the diagnosis of malignancy. He resected this loop of the intestine and reunited the ends by a Murphy button. The portion of the small intestine removed showed that an implantation adenoma of endometrial type had developed on the surface of the intestine, fusing and invading the adjacent walls of the loop (Figs 53, 54 and 55). A similar adenoma invaded the appendix at its junction with its mesentery (Fig 56). There was a similar lesion in the right ovary and a hematoma of endometrial type, as already mentioned. Figure 57 shows a common normal relation between the right ovary, the terminal loop of the ileum and the appendix. The contents escaping from a perforation of a hematoma of the right ovary might easily soil the appendix and terminal loop of the ileum and give rise to the implantation adenomas above described.

*CASE 4—Implantation adenoma (of endometrial type) of the sigmoid, posterior wall of the uterus, both broad ligaments, tubes, left ovary, large hematoma (of endometrial type) of the right ovary with evidence of a previous perforation.* Mrs W A F, aged 28, complained of severe pain at the menstrual periods. She had one child, 6 years old, and she had had a miscarriage three years previously. Menstruation had been regular and free from pain until the last year. Since then she had had pain, worse on the right side, gradually increasing in severity. The last few months the pain was so severe that she was confined to her bed for two or three days. Constipation was increased during the menstrual period and bowel movements were associated with great pain at that time. The patient was operated on two weeks after the last menstrual flow. Pelvic examination demonstrated the uterus to be of normal size, pushed forward and to the left by a cystic tumor which filled the pelvis and seemed to be adherent. On rectal examination a definite localized area of induration could be felt in the anterior wall of the rectum. The rectal mucosa was freely movable over it. The preoperative diagnosis was perforating hemorrhagic cyst of the ovary with implantations in the culdesac.

At operation at the Albany Hospital, May 5, 1921, there was found a cyst of the right ovary, about 8 cm in diameter, which filled the pelvis, pushing the uterus forward and to the left (Fig 3). This cyst was densely adherent to the bottom of the pelvis and when it was freed a large amount of "chocolate" fluid escaped. Implantation adenomas of endometrial type were found involving the wall of the sigmoid, its epiploic appendages and mesentery, also the posterior wall of the uterus, broad ligaments and tubes (Figs 4 to 13). The appendix, both ovaries, tubes and the entire uterus were removed.

The cyst of the right ovary was bilocular, with a larger loculus communicating with a smaller one. It was lined by cuboidal to columnar epithelium of endometrial type, with an underlying stromal hemorrhage. An occasional gland was found in the stroma. The epithelium lining the cyst was similar to that found in the implantations (Figs 11 and 12) and in places the epithelium had apparently been removed by the blood beneath it rupturing into the cavity of the

cyst There was evidence of a previous perforation, through which blood containing the epithelium above mentioned might escape into the peritoneal cavity, and wherever it would lodge, this epithelium might grow and give rise to the deposits of endometrial tissue found in the pelvis of this patient I believe that this occurred

The patient made a satisfactory convalescence I examined her last in July, 1921 The area of induration was still present in the anterior wall of the rectum but was apparently smaller

CASE 5—*Implantation adenoma (of endometrial type) in the culdesac, fusing the anterior wall of the rectum with the posterior wall of the cervix, large*

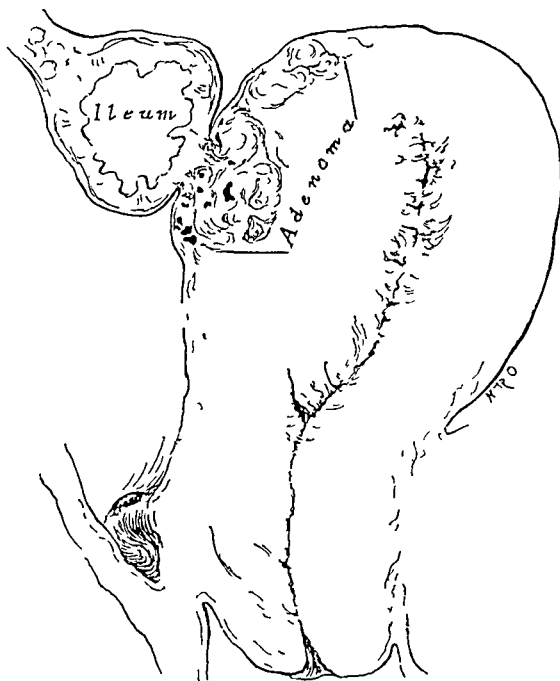


Fig 59 (Case 12)—Sagittal section of the uterus taken a little to the right of the median line indicating its relation to the ileum prior to the last operation,  $\times \frac{3}{4}$  My interpretation of the etiology of this condition is as follows At the previous operation, four years ago, some of the epithelium lining the hemorrhagic cyst of the left ovary became implanted on the posterior surface of the uterus and other portions of the pelvic contents and developed into implantation adenomas of endometrial type The ileum became adherent to the implantation on the posterior surface of the uterus and was superficially invaded by it (Fig 60) The uterine wall was invaded to a much greater extent as indicated in this illustration and the next I believe the preservation of the right ovary was responsible for the development of the adenoma from the implanted epithelium

*hematoma (of endometrial type) of the left ovary with evidence of a previous perforation* Miss E C, aged 39, complained of profuse menstruation associated with pain Menstruation had been regular, normal and free from pain until about six months previously Since then it had gradually increased in amount and was accompanied with pain The last menstrual period occurred a week before the operation The patient was constipated but this was not any worse during menstruation Pelvic examination demonstrated the uterus

to be irregularly enlarged, filling the pelvis and extending upward almost to the level of the umbilicus. The preoperative diagnosis was a multinodular myomatous uterus. The ovarian hematoma was mistaken for a subserous myoma, and the adenoma in the culdesac was not detected.

At operation at the Albany Hospital, May 7, 1921, the uterus was found to contain several leiomyomas. The right ovary was normal in appearance while the left was replaced by a cystic tumor about 6 cm. in diameter, densely adherent to the left half of the lower portion of the pelvis. The bottom of the culdesac was obliterated by the fusion of the anterior wall of the rectum to the posterior wall of the cervix, and on drawing the uterus upward, the rectum was carried with it in a characteristic manner (Fig 14). The portion of the anterior wall of the rectum which was attached to the cervix was indurated and pigmented blebs were present on its free surface about the line of fusion with the cervix (Fig 14). When the ovarian hematoma was freed, its wall was torn and a large amount of "chocolate" fluid escaped. A small amount of similar fluid escaped when the rectum was freed from the cervix. The appendix, left tube and ovary and entire uterus were removed. The right tube and ovary were not removed, against my better judgment, because the patient was most insistent that ovarian tissue should be preserved. Histologically, the posterior wall of the cervix showed a characteristic adenoma of endometrial type. The ovarian hematoma was for the most part lined by a pigmented layer, the result of previous hemorrhage without an epithelial covering. Epithelium of endometrial type was found in depressions of this pigmented layer near the hilum of the ovary and also structures resembling uterine glands (Figs 16 and 17). The patient made a satisfactory convalescence and has remained well. I am awaiting with interest the ultimate outcome, as adenoma of endometrial type was left in the anterior wall of the rectum and the remaining ovary may stimulate it to further growth.

*CASE 6—Implantation adenoma (of endometrial type) in the culdesac, in the wall of the appendix and in its mesentery, tubules (of endometrial type) in the right ovary with evidence of a previous hemorrhage in the surrounding ovarian stroma, multiple leiomyomas of the uterus, cholelithiasis.* Mrs. P. K., aged 42, complained of profuse menstruation and severe indigestion. She had been married twelve years but had never been pregnant. Menstruation was regular, free from pain and had been very profuse for the last four or five months. The last menstrual flow occurred three weeks before the operation. On abdominal palpation the right side of the abdomen was distinctly tender, the tenderness extending well up toward the costal margin. Pelvic examination revealed a nodular pelvic tumor, apparently arising from the uterus and extending about half way to the umbilicus. The preoperative diagnosis was a multinodular myomatous uterus and chronic appendicitis or cholecystitis.

At operation at the Albany Hospital, May 24, 1921, the uterus was found to be irregularly enlarged by several leiomyomas. The gallbladder was palpated and found to contain gallstones. The appendix, which was slightly adherent, was first removed. The right ovary was also lightly adherent to the side of the pelvis. Both tubes and ovaries and the entire uterus were removed. A small area of induration with pigmented spots was noticed in the culdesac. This was excised and found to be an adenoma of endometrial type. The gallbladder was also removed. Two small pigmented areas were noticed on the lateral and free surface of the right ovary. Histologically, the pigmentation was found to be due to cells containing old blood pigment, the evidence of previous hemorrhage into the tissues of the ovary. In this area glandlike

structures were found, some of which were dilated (Fig 51) Some of the cells lining these spaces were ciliated These areas might be interpreted as the remains of a small ovarian hematoma of endometrial type which had perforated, and most of the epithelium had been destroyed In the repair which followed, some of the epithelial cells which had remained had proliferated, giving rise to these glandlike structures surrounded by the pigmented cells, the evidence of old hemorrhage Dr Thomas Ordway called my attention to glandlike structures in the wall of the appendix (Fig 50) They were similar to those in the ovary, even to the presence of ciliated cells There was not any evidence of hemorrhage into, or about, the glandlike structures of the

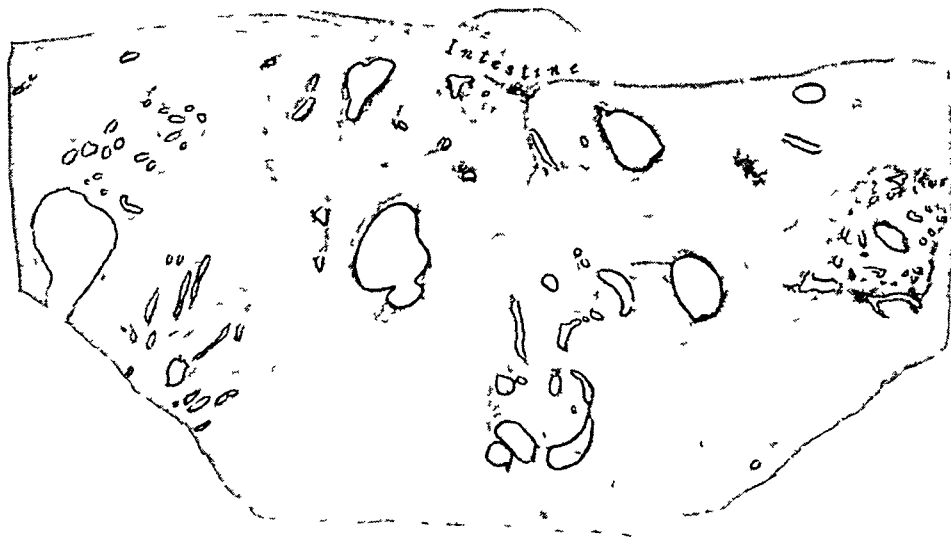


Fig 60—Adenoma of endometrial type of the posterior uterine wall and superficially invading the wall of the ileum which is fused to the uterus at this place Section of a portion of the wall of the ileum which is fused with (drawn into) the uterine wall at this situation I believe the implantation developed on the posterior wall of the uterus indicated by the depression beneath the piece of intestine attached to it It only superficially invaded the wall of the intestine but has extensively invaded the uterine wall, giving rise to a typical so-called adenomyoma of the uterus, not arising from the direct invasion of the uterine mucosa from the uterine cavity or from the developmental inclusions of müllerian epithelium in the uterine wall or from a metaplasia of the peritoneal mesothelium but from the implantation of endometrial epithelium from the epithelial lining of a perforated hemorrhagic cyst of the ovary (of endometrial type), as probably the majority of the ectopic pelvic adenomas (of endometrial type) shown in this and the previous communication arose (For another possible source of implantation adenomas of endometrial type, see text )

appendix What was the relation between the adenoma in the ovary to that in the appendix and culdesac? A small ovarian hematoma of endometrial type which had perforated, thus scattering some of its epithelial lining, would account for the involvement of the appendix and culdesac The apparent remains of such a hematoma were found in the ovary

*CASE 7—Implantation adenoma (of endometrial type) in the anterior wall of the sigmoid, similar adenomas involving the epiploic appendages also on*

the posterior uterine wall and right ovary two hematomas (of endometrial type) of the left ovary, one not perforated, the other with evidence of a perforation, retroflexed uterus, leiomyoma and weakened pelvic floor—Mrs J L, aged 44, complained of uterine bleeding and a sense of lack of support. She had one child 20 years old. Menstruation had been regular, at times profuse, but without pain. She had been flowing almost continuously for more than two months and had lost a large amount of blood. She was constipated but not more so during the menstrual period. Pelvic examination revealed a weakened pelvic floor, a small cervical polyp, a retroflexed uterus, slightly enlarged and very hard. The preoperative diagnosis was a weakened pelvic floor, cervical polyp, retroflexed uterus with myofibrosis, an intramural or submucous myoma.

Operation at the Albany Hospital, July 8, 1921, demonstrated the uterus to be enlarged, retroflexed and freely movable. The left ovary was densely adherent to the side of the pelvis, and when it was freed, a small amount of "chocolate" fluid escaped. The peritoneum of the anterior surface of the lower sigmoid was in places thickened and white as though scar tissue had arisen from some irritating substance which had "burnt" it. On one of these scarred areas there was a small hemorrhagic bleb (Fig 37), which was excised. Two of the epiploic appendages on either side of this area were adherent to each other, as though they had been ligated (Figs 37 and 39). These were removed. The appendix, both tubes and ovaries and the entire uterus were removed and the pelvic floor was repaired. The hemorrhagic bleb embedded in the sigmoid was lined by low to cuboidal epithelium and its cavity was filled with old blood. I believe it was a hematoma of endometrial type. The fused epiploic appendages were invaded by tubules of endometrial type (Fig 39). The hematoma of the left ovary with evidences of perforation could have given rise to the implantation. The implantations on the uterus and right ovary were adenomas of endometrial type. The two hematomas of the left ovary were typical hematomas of endometrial type. The patient developed a postoperative intestinal ileus which was relieved by an enterostomy. Otherwise she made a satisfactory convalescence.

CASE 8—*Implantation adenoma (of endometrial type) of the sigmoid and the posterior and anterior surfaces of the retroverted uterus, large hematoma (of endometrial type) of the left ovary with evidence of a previous perforation.* Mrs F W T, aged 47, complained of pain in the left lower abdomen and constipation at the menstrual periods. She had had one child, ten years ago. Menstruation was moderate in amount and always associated with some pain. This pain had gradually increased in severity during the last three years and especially during the last four months. The pain had been so severe during the last four months that she was forced to spend one or two days in bed. The pain was worse on the left side. Constipation had been increasing and was worse during menstruation. The patient did not have any pain between the menstrual periods. Pelvic examination demonstrated the uterus to be retroflexed and fixed in the pelvis with an adherent cystic mass, the size of a small orange, occupying the region of the left ovary. The bottom of the culdesac (best detected on rectal palpation) felt slightly nodular. The preoperative diagnosis was a probable, perforated hematoma of endometrial type of the left ovary, with implantations in the culdesac and adherent retroverted uterus.

At operation at the Albany Hospital, July 21, 1921, the uterus was found to be retroverted, with the sigmoid adherent to the fundus. Small peritoneal cysts with encapsulated blood were found on the surface of the uterus at the junction

of the fundus and adherent sigmoid and one on the anterior surface of the uterus below the origin of the left round ligament. There was a similar bleb on the mesentery of the sigmoid at the pelvic brim and a characteristic lesion on the anterior surface of the sigmoid (Figs 26 and 27). The uterus was adherent to the sigmoid and rectum, posteriorly. When the densely adherent ovarian hematoma was freed, its wall was torn and a large amount of "chocolate" fluid escaped. The wall of the hematoma was so densely adherent to the side of the pelvis that it was removed in fragments. Both tubes were apparently patent and the right ovary seemed normal. An indentation was found in the wall of the lower sigmoid, with thickening of the tissues about it and characteristic small pigmented areas on the surface of the intestine (Fig 27). The appendix, both tubes, ovaries and the entire uterus were removed. The implantations in the sigmoid were not disturbed. The greater portion of the posterior wall of the uterus was superficially invaded by an endometrial adenoma. Similar tissue was found in the anterior wall of the uterus beneath the small hemorrhagic

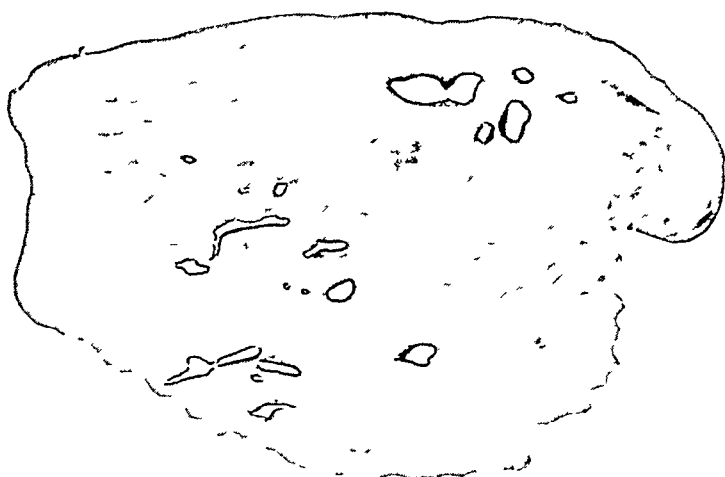


Fig 61 (Case 12)—Cross-section of the left uterosacral ligament showing that it is invaded by an adenoma of endometrial type, the dilated tubules of which were distended with menstrual blood prior to the operation

cysts. I believe the blood in the cysts arose from the underlying adenoma and was menstrual. Sections of the wall of the left ovarian hematoma showed that it was lined by pigmented tissue resulting from previous hemorrhages. The epithelium, for the most part, was lacking, except near the hilum of the ovary. The hematoma of the left ovary with evidence of perforation could have been the cause of all the implantations. The patient made a satisfactory convalescence and has remained well.

CASE 9 (Dr Elting's case)—*Implantation adenoma (of endometrial type) of the appendix and posterior uterine wall, hematoma (of endometrial type) of both ovaries with evidence of perforations.* September 30 of this year, Dr A. W. Elting showed me a specimen of the uterus, tubes, ovaries and appendix, which he had just removed and had correctly interpreted as one of implantation adenoma with perforated hemorrhagic cysts of both ovaries. He gave me permission to study the specimen and it is through his courtesy that I am reporting the case.



Mrs R, aged 47, complained of abdominal pain. She had had one child, twenty-three years previously. Two years ago she had an attack of pain in the lower abdomen, the symptoms suggesting peritonitis. She had a similar attack, September 5, of this year, beginning on the first day of the menstrual period. At the operation at the Albany Hospital, Sept 30, 1921, Dr Elting found the intestines and omentum stained a dirty brown (old blood), this was most marked in the pelvis. The uterus was firmly adherent to the rectum. He removed the uterus, tubes, ovaries and appendix. Both ovaries contained typical hematomas of endometrial type with evidence of a previous perforation. Implantation adenoma of endometrial type was present on the posterior surface of the uterus, which it had invaded. The surface of the appendix was studded with reddish elevations which histologically proved to be implantations of typical uterine mucosa (Figs 47, 48 and 49). The hemorrhage into the peritoneal cavity undoubtedly arose from menstrual blood escaping from the implantations, the ovarian hematomas or both. It is most significant that the present attack of abdominal pain occurred on the first day of the menstrual period. The ovarian hematomas with evidence of a previous perforation could have given rise to the implantations.

*CASE 10—Implantation adenoma (of endometrial type) of the rectum, rectovaginal septum, epiploic appendage of the sigmoid, mesentery of the appendix, tubes, posterior layers of the broad ligaments and posterior uterine wall, hematoma (of endometrial type) of both ovaries, evidence of a previous perforation of the hematoma of the right ovary, multiple leiomyomas of the uterus.* Mrs W W C, aged 40, complained of severe dysmenorrhea and pressure sensations in the rectum, the latter most marked during the menstrual flow. She had been married thirteen years but had never been pregnant. Menstruation had always been painful, gradually increasing in severity during the last year and especially during the last four months. The amount of the flow had increased during the last year. Backache and pressure sensations in the rectum were most marked the third and fourth days of the flow and lasted for a week after the flow ceased. Constipation had also increased the last year but was not always worse during the menstrual flow. The patient was operated on four days after the last menstrual period. Pelvic examination demonstrated the uterus to be irregularly enlarged and fixed in the pelvis. There was marked irregular induration in the culdesac, with an oblong mass the size of one's thumb extending down between the rectum and vagina to the right of the cervix (Fig 25). The preoperative diagnosis was implantation adenoma of endometrial type in the culdesac with extension downward to the right of the cervix in the rectovaginal septum, multiple leiomyomas of the uterus and probable perforated hematoma of endometrial type of the ovary.

At operation at the Albany Hospital, Oct 22, 1921, the uterus was found to contain several leiomyomas. On drawing it upward and forward the anterior rectal wall was carried with it, as it was fused with the posterior wall of the uterus. The right ovary was enlarged and adherent to the posterior layer of the right broad ligament. Small pigmented cysts were found on the posterior wall of the uterus, on the anterior wall of the rectum just above the line of fusion with the uterus, and also on the posterior layer of the right broad ligament along the line of fusion with the ovarian hematoma. Implantations were also present on the posterior layer of both broad ligaments just beneath the tubes (Fig 19). The appendix was removed. On freeing the right ovary from its attachment to the posterior layer of the right broad ligament, "chocolate" fluid escaped. The uterus was separated from the rectum with great difficulty. Both



Fig 62 (Case not reported in this series) —The development of a small perforated hematoma of endometrial type from glands or tubules of endometrial type in the ovary which react to menstruation. These three drawings were made from different parts of the same ovary. Section *A* shows a gland or tubule lined by columnar epithelium, some of which is ciliated. (The probable origin of such a gland is discussed in the text.) The dark area to the left of the gland indicates a stromal hemorrhage. Section *B* shows a later stage, the tubule or gland has become larger. It is now a small cyst lined by epithelium of endometrial type with stromal hemorrhage all about it and evidence that, previously, some of the blood in the stroma had escaped into the cavity of the cyst. This cyst is gradually approaching the surface of the ovary and perforation would probably occur before it becomes much larger. Section *C* shows one of these cysts which has perforated, one half the magnification of *A* and *B* and from the same section as that shown in Figure 52. Some of the blood in the stroma surrounding the cyst had broken through into its lumen, carrying with it some of the overlying epithelium. Perforation had occurred into the peritoneal cavity and some of the contents of the hematoma, including epithelial cells, escaped through the perforation and might have given rise to implantation adenomas of the same type as the epithelium lining the cyst. Implantation adenomas of this type were present in this case where the contents from such a cyst would be likely to fall. The cyst *C* is only partly lined by epithelium which is low to columnar and only a few ciliated cells were found. I believe that the larger hematomas or hemorrhagic cysts shown in this paper arose from similar glands and tubules situated deeper in the ovary.

tions on the sigmoid and rectum, an ovarian hematoma, with evidence of a previous perforation, was situated in the left ovary in six, while in the four instances of implantation on the appendix, a similar hematoma was situated in the right ovary in all four. This suggests that while the intestinal implantations from either ovary may be general in their pelvic distribution, the portion of the intestinal tract normally situated near that ovary is more likely to be involved.

The character of the intestinal lesions varies greatly, and they may be grouped as follows:

1 Surface and superficial implantations

(a) Subperitoneal glands and tubules of endometrial type with evidence of hemorrhage into the tissues about them or in the lumen of the glands or tubules. The surface of the intestine involved is thickened and the brown pigmented dots (1 to 2 mm in diameter) and larger elevated areas due to the hemorrhage (menstrual) can be easily detected at operation.

(b) Endometrial tissue on the surface of the intestine including polyps, which often appear hemorrhagic.

(c) Subperitoneal hematomas, a later stage of Group *a*.

(d) Encysted menstrual blood which had escaped from an underlying endometrial implantation.

2 Implantations developing between adherent folds of peritoneum and other adherent structures (pocketed implantations), best seen in the culdesac between the posterior wall of the uterus and the rectum, which are often fused together. The surface of the adherent parts, which are exposed after separating them, often have a characteristic "pitted" appearance due to the exposure of endometrial tissue in the pockets between the adhesions or in the deeper tissues of the organ involved.

3 The deep invasion of the underlying structure or organ. The tubules worm their way into the tissues of the intestine, and this is often associated with a marked hypertrophy of the surrounding connective tissue and muscle. Many varieties of endometrial tissue and its derivatives may be found, including glands and tubules with and without a characteristic endometrial stroma, dilated tubules, miniature uterine cavities, hematomas and the invasion of lymph vessels by endometrial polyps.

As in implantation carcinoma these implantations may occur on any part of the intestine, its peritoneal surface, its mesentery and especially the epiploic appendages of the sigmoid. The latter may serve as a portal of entry to the deeper tissues of the wall of the intestine.

The intestinal lesions are often only of histologic interest and do not give rise to any symptoms. In other cases the lumen of the

intestine is encroached upon by indentations, by hypertrophy of its walls, and by hematomas, the latter may become larger during menstruation so that symptoms of obstruction may only occur or be more marked at that time

The implantations in the culdesac, including the involvement of the rectum, can often be palpated prior to operation. In typical cases the diagnosis can usually be made before operation. The age of the patient (usually between 30 and the menopause), the acquired dysmenorrhea or recent increase in menstrual pain, the disturbance of intestinal function during menstruation, the detection of a small adherent ovarian cyst or adherent ovary and the palpatory findings in the culdesac present a syndrome rarely furnished by any other condition.

The operative treatment of intestinal adenoma of endometrial type is at present an unsettled problem. My own reaction, at present, on finding what appears to be an intestinal lesion is to examine carefully the surface of the intestine for dots and areas due to hemorrhage, to look for other implantations in the pelvis and most important of all to examine carefully the ovaries for any signs of a hematoma with evidence of a previous perforation, bearing in mind that it may be very small and is most frequently situated on the lateral or the under surface of the ovary. If the evidence found indicates an adenoma of endometrial type I do not disturb the intestinal lesion, except as it may be easily removed for histologic study, but deal with the pelvic organs as their condition requires. Conservative ovarian surgery in these cases leaves behind a possible source of more implantations, and apparently retained ovarian tissue may sometimes stimulate the growth of the implantations which have not been removed.

I believe that an important, and probably the principal, source of these implantations is the epithelium escaping from an ovarian hematoma of endometrial type which has perforated. The majority of the implantations in the twelve cases reported in this series apparently arose from such a source. There is the possibility that some of them may have arisen from tubal and uterine epithelium escaping through the fimbriated end of the tube, independent of an ovarian hematoma with perforation.

Ovarian hematomas of endometrial type arise from glands and tubules of this type in the ovary which react to menstruation. If they are situated on, or near, the surface of the ovary, perforation occurs while they are small and repeated hemorrhage and perforation may carry away all of the epithelium so that they may disappear, or if it is not all removed the ovarian lesion may be so small and inconspicuous that it may be easily overlooked at the operation and also in the labora-

toiy study of the ovary If the endometrial gland or tubule is situated in the deeper tissues of the ovary, then the hematomas reach a larger size before perforation takes place

How does this epithelium of endometrial type reach the ovary? Is it of developmental origin from the inclusion of epithelium of the mullerian or the wolffian ducts or is it acquired during adult life? The evidence which I have, at present, suggests that it is usually (possibly always) acquired from the implantation on the surface of the ovary of tubal or uterine epithelium escaping through the fimbriated end of the tube and possibly from tubal fimbriae in contact with the ovary This epithelium may subsequently invade the tissues of the ovary and later develop into menstruating cysts giving rise to hematomas of endometrial type, the perforation of which permits some of the epithelium, cast off by the menstrual hemorrhage, to escape into the peritoneal cavity and there develop into implantation adenomas of endometrial type I consider the ovary as an intermediary host, hotbed or incubator, which may impart increased vigor and virulence to this epithelium, so that when it escapes from the ovary it may be more virulent (malignant) and invasive than before the hematoma developed and the perforation occurred It may not be an essential intermediary host, for it is possible that pelvic implantations may arise from tubal and uterine epithelium escaping from the tube, and also implantations from both sources may be present in the same case The few cases which I have interpreted as possibly arising from epithelium escaping from the tubes have lacked the vigor, invasiveness and wideness of distribution of the implantations usually found in those associated with an ovarian hematoma with evidence of perforation and also usually present a slightly different histologic picture from the latter This is a problem for further study The larger the hematoma and the greater the perforation the wider the distribution of the implantations and apparently the greater their virulence

Intestinal adenoma of endometrial type is a common condition occurring in more than one half of the cases with ectopic endometrial adenomas and the latter may be found in from 10 to 20 per cent of women between 30 years of age and the menopause who require an abdominal operation for some disease of the pelvic organs On account of its frequency, pathologic interest and clinical importance, it deserves a greater recognition than has been accorded it in the past

# THE AUTOTRANSPLANTATION OF ENDOMETRIAL TISSUE IN THE RABBIT\*

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It has been observed by Sampson<sup>1</sup> that in women between the age of 30 and the menopause a frequent pathologic condition is found which consists in part of the presence of "chocolate" cysts of the ovary. These cysts are lined with ciliated epithelium, are surrounded by stroma like that of the endometrium, and take part in the menstrual cycle in much the same manner as does the uterine mucosa. When a cyst is close to the surface of the ovary, it may, and frequently does, rupture during menstruation, scattering, in the pelvic cavity, epithelial cells of the type lining the cyst and also menstrual blood. The menstrual blood possibly contains a substance which is capable of so altering the peritoneum that the epithelial cells from the cyst may become implanted where the peritoneum is injured, and develop, producing adenoma-like growths, or these cells may invade, from the outside, such structures as the oviduct, uterus, appendix and intestine, and cause a proliferative smooth muscle reaction, thus simulating very closely the so-called adenomyoma. This observation is of extreme interest, and, if correct, should, it seems, be susceptible of experimental demonstration, at least in some of its phases. With the purpose of investigating the matter from this standpoint, five rabbits were subjected to the following operative procedures. The animals were adult females, Belgian hares and Angoras, age unknown, but probably from 8 to 12 months old. All operations were performed under ether anesthesia and with aseptic precautions.

## REPORT OF EXPERIMENTS

EXPERIMENT 1—Four cm of the right cornu was removed from Rabbit 1, about 5 cm from the fimbriated end. The cut ends of the cornu were tied with silk as were the vessels of the broad ligament of the part removed. The excised portion was opened longitudinally and the mucosa thoroughly scraped with a knife. The scrapings were gently rubbed into previously scarified areas of the peritoneum of loops of the small intestine lying in the pelvis. Then this piece of the cornu was cut into very fine pieces, most of them less than 1 mm in size, and about a dozen of these pieces were dis-

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\* From the department of pathology, Albany Medical College, and the pathologic laboratory of Albany Hospital.

\* Read before the American Association of Pathologists and Bacteriologists, Washington, D C, May 3, 1922.

1 Sampson, J A. Perforating Hemorrhagic (Chocolate) Cysts of the Ovary. *Arch Surg* 3 245 (Sept) 1921.

tributed in the pelvis, about the uterus and among the loops of intestine. Some blood (a few cubic centimeters) was allowed to escape into the pelvis. The abdominal wound was closed with through-and-through silk sutures and the animal was allowed to recover. It was kept alone in a cage for nine weeks and then was killed with ether. Necropsy showed (1) hydrosalpinx of the remaining distal 3 cm of the right tube, (2) a multilocular cyst containing clear, thin, colorless fluid in the fat overlying the dilated tube at one point (Fig 1). This cyst was 2.2 cm in diameter and had several chambers lined with a smooth glistening membrane. (3) A multilocular cyst, 2 cm in diameter, in the fat, closer to the fundus uteri (Fig 2), (4) a cyst, 2 mm in diameter, attached to the serosa of the left tube (Fig 3).

*Histologic Examination*—An implanted piece of tissue in the mesentery of the right tube resulted in the formation of a multilocular cyst, 2.2 cm in



Fig 1 (Rabbit 1)—Right cornu opened, showing hydrosalpinx and, in the fat of the mesosalpinx, a multilocular cyst in which can be seen a polypoid ingrowth.

diameter. It was lined by low to high columnar ciliated epithelium. Polypoid ingrowths had occurred (Fig 5), a few were fairly large, with a stroma of loosely arranged spindle cells and numerous thin walled blood vessels. The epithelium covering the polyp was hyperplastic, sending tortuous processes down into the substance of the polyp. Mitotic figures were present in the epithelial cells in moderate numbers (Fig 6). The cyst was partially surrounded by thin layers of smooth muscle, which were abruptly broken at several points. Between the epithelial lining and its supporting stroma was a layer of collagen fibers and fibroblasts which formed a sort of submucosa. The muscle bundles passed in many directions and ended in the surrounding adipose tissue. Mitotic figures were present in some of the muscle fibers. Fat cells had apparently grown in between fibers of traumatized muscle fasciculi. Fibroplasia in the adjacent fat was marked and clasmotocytes and eosinophils

were found in small numbers between the fat cells. No nerves were seen in the cyst wall. The peritoneum had covered the defect produced at operation and no evidence of downgrowth to the cyst was observed.

In Figure 2 the superficial nubbins on the fat is almost a reproduction of a tube, there being in addition to the epithelial lining a surrounding layer of regenerating smooth muscle which, however, is not laid down in so orderly a manner as in the normal tube.

The large cyst which was continuous with the growth just described was lined by ciliated, low to high columnar epithelium. Some of the cells were not ciliated but these were of low and apparently immature type. There were polypoid ingrowths, with numerous dilated gland spaces along their bases. The stroma of the "mucosa" was of endometrial character. The glands had no basement membrane. Mitotic figures were found in both epithelium and smooth

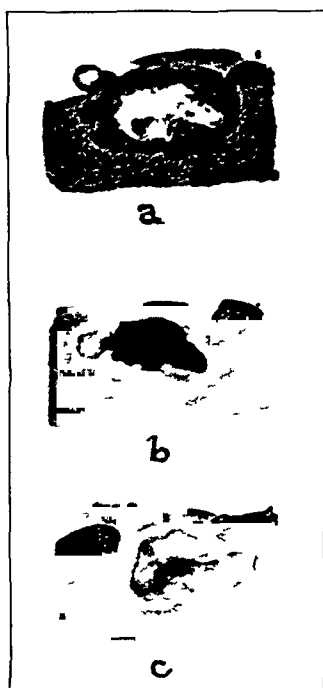


Fig 2 (Rabbit 1) —Another multilocular cyst in the mesosalpinx, apparently arising by downgrowth of epithelium from the superficial nubbins in *a*

muscle. There was a marked proliferation of fibroblasts and infiltration by wandering cells in the fat surrounding the cyst.

The cyst in the fat over the left cornu (Fig 3) was lined with low columnar epithelial cells, some of which were ciliated. Very little stroma separated it from the subjacent, dense fibrous tissue in which were a few smooth muscle fibers (Fig 4). The cyst was separated from the cornu proper by a wide interval of fat which showed much invasion by fibroblasts about the cyst. The peritoneum overlying the cornu and cyst was not involved in the formation of the cyst.

EXPERIMENT 2—The mucosa of a portion of the right cornu was removed from Rabbit 2 of the same size and from the same situation as in Rabbit 1. It was dissected off carefully and cut into pieces a millimeter in size or less.



One piece was inserted into the right ovary in each of two places on the anterior surface, through stab wounds. One piece was slipped under the germinal epithelium. Mesentery was wrapped about the ovary and secured with two linen sutures. Eight weeks later, under ether anesthesia, the abdominal cavity was examined. At the site of the right ovary was found a bluish-red mass, about the normal size of the ovary. The fat and tissue about it were firmly adherent and indurated. The wound was closed and in a few days it was healed. The animal was put with a male rabbit in order to study the effect of heat on any cyst which might develop. Eight days later, the animal died from severe coccidiosis. No pregnancy had developed. The left ovary and cornu were normal. There was right hydrosalpinx, and at the site of the right ovary a mass, 1.5 cm in diameter, parts of which were yellow and opaque, but as a whole it was cystic, with fibrous adhesions firmly matted around it.

*Histologic Examination*—Occupying the greater part of the substance of the ovary were two cystic cavities, the larger 1 cm in diameter, the smaller about 0.5 cm (Fig 8). The larger cyst was surrounded by ovarian tissue, except on its posterior surface, where the peritoneum and subserous fibrous layer alone covered it. Serial sections demonstrated that the cyst approached close to the upper peritoneal surface. It was lined with cuboidal to columnar epithelium which in many places was ciliated, and here and there thrown into



Fig 3 (Rabbit 1)—Gross appearance of the cyst in the fat overlying the left cornu

very low rugae. No mitotic figures were seen. Epithelial buds in the form of small tubules were plentiful beneath the lining membrane. At one point, a small polyp projected into the cavity. The polyp was covered with high columnar epithelium, each cell being densely ciliated. Small masses of erythrocytes and a few hemosiderin-laden phagocytes were present in the lumen. The stroma of the polyp was edematous fibrous tissue, with numerous fine capillary vessels.

The stroma of the subepithelial layer of the cyst was composed of rather closely packed collagen fibers and flattened spindle cells, and surrounding this layer was a thicker layer of smooth muscle fibers and collagen.

The smaller cyst on one side lay apposed to ovarian tissue, but its growth had apparently been in great part subperitoneal. It was quite similar to the larger cyst, with the exception that not so many of its lining cells were ciliated.

The ovarian tissue contained a multitude of primordial follicles of many sizes, and corpora lutea were also very numerous. Several narrow spaces just beneath the peritoneum and also deeper in the ovary were lined with non-ciliated cuboidal cells which were undoubtedly peritoneal in origin. In several places, in the vicinity of the two large cysts, were large numbers of mononuclear phagocytes filled with hemosiderin.

These two cysts were in all probability derived from the transplanted endometrial tissue, as they were like the cysts found by similar transplantation into the fat of the mesosalpinx, being lined with ciliated epithelium which had formed irregular folds and polypoid ingrowths and with stroma composed of fibrous tissue and smooth muscle

EXPERIMENT 3 — The mucosa was dissected from 2 cm of the excised portion of the left cornu from Rabbit 3, and cut up into millimeter-sized pieces. With the point of an eye knife, three stab wounds were made in the anterior serosal surface of the fundus uteri, and with fine forceps, two



Fig 4—Low power photomicrograph of a transverse section through the cyst and cornu shown in Figure 3

pieces of cornual mucosa were inserted beneath the serosa. There was slight bleeding from these wounds. The left mesosalpinx was brought over the wounded surface and held in place by a linen stitch on the right side of the uterus. Nine weeks later the animal was killed with ether. On the anterior surface of the uterus were found two glistening cysts, 0.5 and 1 cm in diameter, respectively. These cysts appeared to be somewhat adherent to the wall of the fundus. There were focal indurated areas in the fat of the mesosalpinges. On section these areas were found to contain cysts (Fig 9).

*Histologic Examination*—Fundus Uteri Where the wall had been traumatized by the knife, fibrous tissue had grown into the defect, with subsequent puckering produced by the scar No epithelial growth was found in serial sections proceeding outward from the mucosa or inward from the serosa The pieces of tissue which had been planted beneath the serosa had apparently become loosened from their positions and had wandered out in the pelvic cavity where they became attached at the following points Two cysts lay closely apposed in the fat overlying the fundus Their walls were very thin, that of the larger being about 0.5 mm and of the smaller about 0.9 mm in the fixed specimen Where the cysts were in contact with each other, their walls increased in thickness to about 1.2 mm In the larger cyst was an



Fig 5—Photomicrograph of a section through *b* in Figure 2, showing polypoid growths into the lumen of the cyst Much smooth muscle is present in the wall of the cyst

albuminous precipitate and a small amount of recent hemorrhage with a moderate number of polymorphonuclear neutrophils and mononuclear phagocytes The cyst was lined with a single layer of epithelial cells, which in the thinnest parts were flattened, but where the wall was thicker, they were low to high cuboidal Many of these cells had rounded knobs which might have been a precursory stage of cilia Rarely a cell was found with well developed cilia There were numerous shallow glandlike downgrowths of epithelium, and the stroma about these was composed of fairly large spindle cells, with large vesicular nuclei Beneath this layer, which was quite thin, were arranged bundles of smooth muscle fibers in a circular manner, and outside

the circular layer these fibers were found lying in many different planes. The wall of this cyst was well supplied with thin walled blood vessels. The surrounding fat showed very little fibroplastic reaction.

The smaller cyst differed from the larger in being lined with epithelial cells of a higher type, and in one quadrant a polypoid growth extended into the lumen. This growth was 1 mm in size and was covered with low columnar epithelial cells which had a knobbed free surface. The nuclei lay in the basal portion, many were hyperchromatic, a few, in mitosis. The stroma was composed of fibroblasts and newly formed blood vessels and a few polymorphonuclear neutrophils and eosinophils were present. A few tubular ingrowths pro-

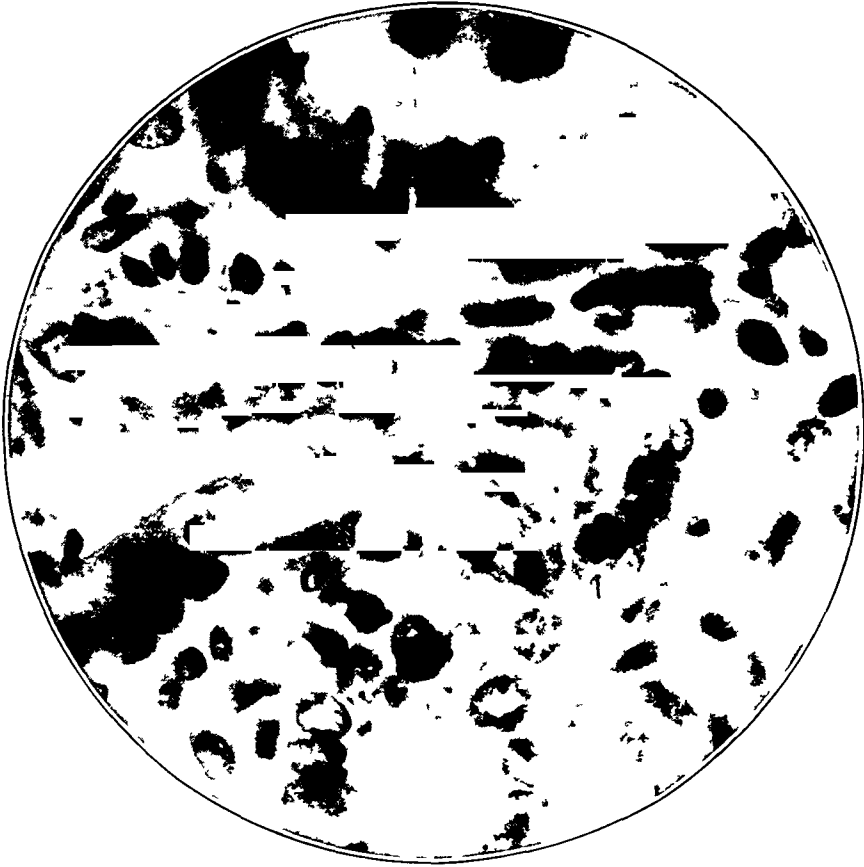


Fig 6—High power photomicrograph of part of the lining of the infoldings in Figure 5. Numerous ciliated cells are shown and the arrow points to an epithelial cell in mitosis.

ceeded from the surface into the center of the polyp. The stroma of the lining membrane was similar to that of the larger cyst, and surrounding it were bundles of smooth muscle lying in many planes as in the former.

In the fat of the mesosalpinx was a multilocular cyst (Fig 9 *b*), about 3 cm from the fundus, and of practically the same structure as those just described, although the larger cavities had a single layer of flattened epithelium for lining, with no evidence of cilia. The wall consisted of fibrous tissue bundles intertwined with smooth muscle fibers. It contained a clear fluid, but no blood. This cyst was embedded in the fat of the mesosalpinx, but there was very little reaction in the surrounding fat, only a narrow zone of fibroplasia.

Lying in the right mesosalpinx fat, at another point, was a multilocular cyst, nearly 3 cm. in diameter (Fig. 5a). It contained about six chambers, all but two of which communicated with one another. The wall varied in thickness from a fraction of a millimeter to 3 mm. Papillary ingrowths had occurred and these consisted of a stalk of delicate fibrovascular stroma covered with cuboidal to columnar epithelium in single or double layers. Small groups

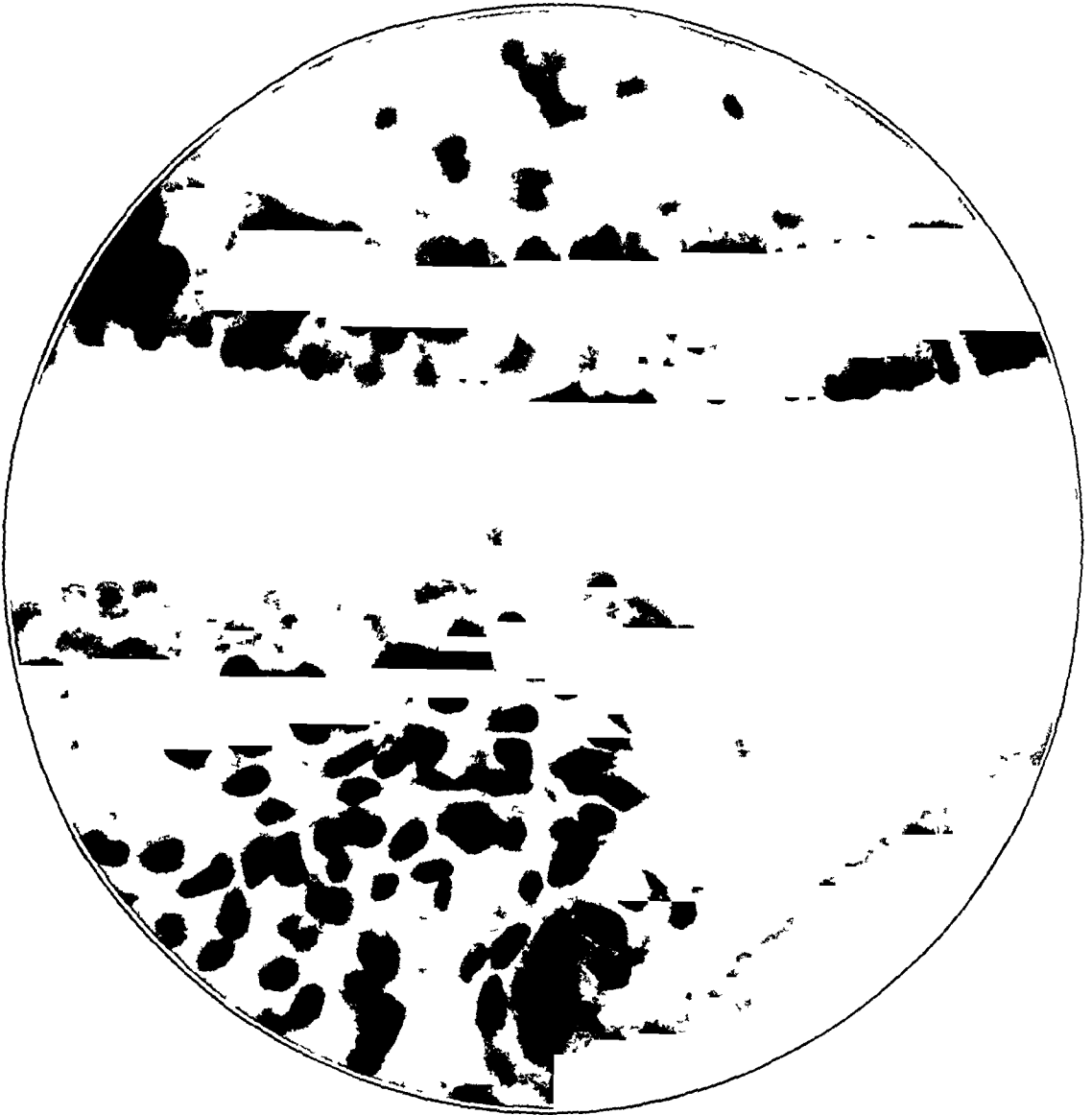


Figure 7—Another portion of the wall of the cyst in Figure 5, showing the columnar epithelium, many cells ciliated, and many having on their free surfaces knobs which may be precursors of cilia

of epithelial cells had invaded the stroma in several places. The subepithelial layer elsewhere consisted of closely packed short spindle cells, somewhat similar to those of the endometrium. A layer of smooth muscle, about six cells in thickness, surrounded this cystic growth and this in turn was surrounded by a band of collagen fibers.

EXPERIMENT 4—At operation on Rabbit 4, midterm pregnancy was found, with four fetuses in the left cornu and two in the right cornu. The dilated portion of the right cornu containing the distal fetus was extirpated, and the pieces *a* and *b* (Fig 10) were removed, about 1.5 cm each, from which the mucosa was dissected free. Very fine pieces of mucosa were inserted into the right mesosalpinx in two pockets, about 1 cm deep. The animal was then

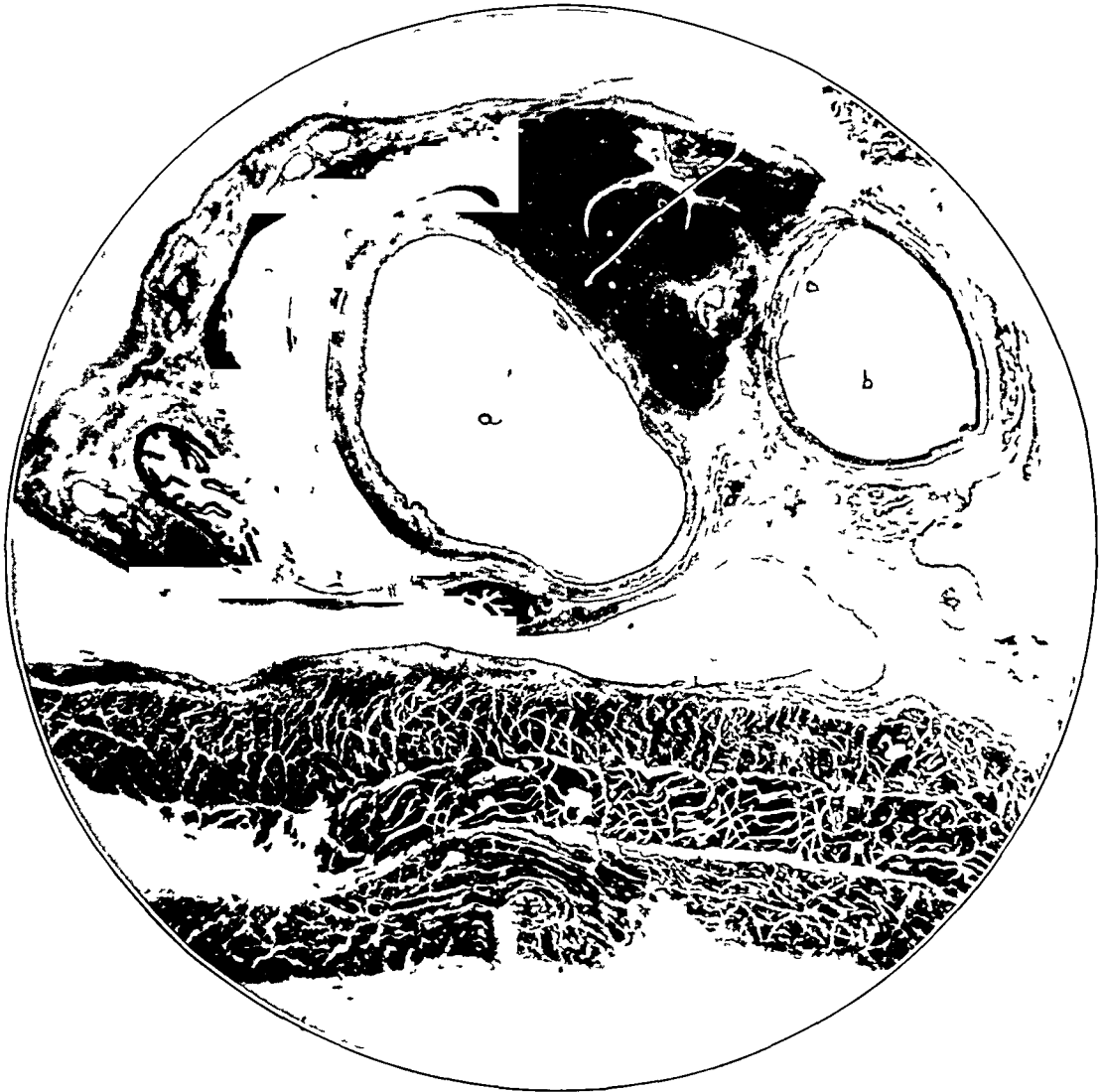


Fig 8—Low power photomicrograph of the right ovary of Rabbit 2, showing two cysts, *a* and *b*, which resulted from the endometrial tissue implanted in the ovary.

put in a cage containing a male rabbit. Seven weeks later an exploratory operation was performed. No mature fetuses were found, the animal having delivered and probably eaten them, several weeks before. Both cornua were, however, congested, an early pregnancy undoubtedly existing in the left but none in the remaining 3 cm of the right. The mesenteric fat of the right cornu was indurated in an area 1.5 cm in diameter, in the portion nearest the fundus and

a reddish discoloration was visible through the fat in this area. The fundus, viewed posteriorly, showed adherent to it a slightly reddish firm mass, 3 mm in size but of irregular outline. The animal was again allowed to recover. Ten days later it was killed.

Necropsy disclosed two well developed fetuses in the left cornu, but none in the right. There was no visible evidence of infection. The anterior uterine wall was adherent to the abdominal wall along the line of the scar. There was a strawberry-like protusion of the mucosa of the stump of the right cornu. Cysts, about 2 mm in size, each filled with clear fluid, were found in the fat

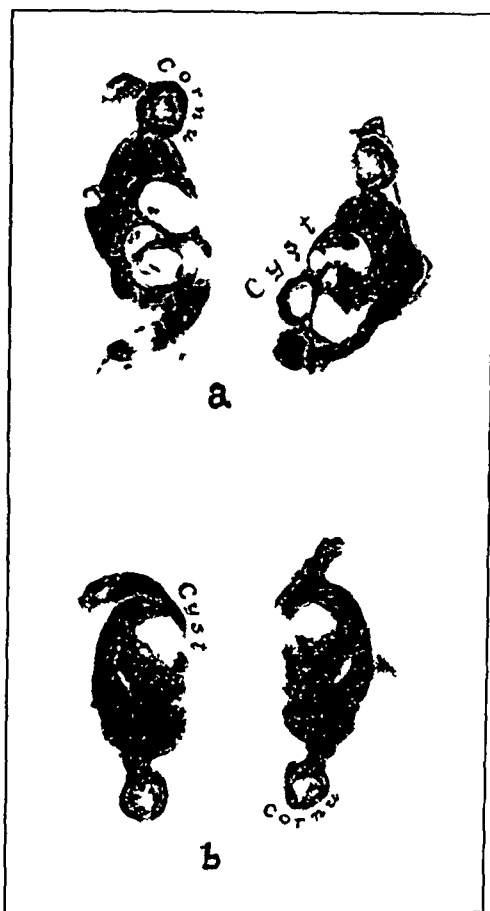


Fig 9—Photograph of gross specimen, slightly retouched, of two cysts in the mesosalpinx of Rabbit 3. The cyst *a* is multilocular.

of the right mesosalpinx in three different places. These cysts appeared to be multilocular and lined with a glistening membrane. A firm mass, about a centimeter in size, was found quite adherent to the right posterior surface of the fundus below the entrance of the cornu.

*Histologic Examination*—The cyst *A* in Figure 9 was embedded in the fat of the right mesosalpinx, about 0.5 cm from the cornu, and had no connection with the cornu. It was composed of many chambers, four of macroscopic dimensions, and a great number of microscopic cavities. The smaller cysts were formed by the anastomosing of very narrow fibrous septums which were covered by a single layer of much flattened epithelium. The larger cavities

in places had a stratified lining of epithelial cells of from four to six layers, some being ciliated, although low cuboidal in type. The stroma consisted of a collagenous reticulum with small bundles of smooth muscle fibers here and there, frequently lying near a cyst and following the cyst's contour. Many thin walled blood and lymph vessels were present. In many places, the stroma had been invaded by small groups of epithelial cells, and about them fibroblasts had taken on increased activity and a slight lymphocytic reaction had occurred. These smaller masses of epithelium usually showed a lumen and their own arrangement at times suggested a syncytium (Fig 12). Surrounding the entire growth was an irregular border of fibrous tissue which penetrated between the adjoining fat cells in delicate branches.

Another cyst found in the right mesosalpinx was also multilocular, and its structure was essentially the same as the growth just described, except that there had been less invasion of the stroma by the epithelial tissue.

The formations in Figures 11 and 13 differed markedly from those in the other two growths (Fig 14). The former are, to all intents and purposes, multilocular cysts lined by flattened epithelium, some of which is ciliated. One of the latter may be considered a multilocular cyst, but with an epithelium of a higher type and much more deeply staining. Each of the cells had a very



Fig 10—Diagram showing the source of the tissue used in transplantation in Rabbit 4. Endometrium from pieces *a* and *b* were used.

large nucleus which occupied fully two thirds of the cell. A great many of the cells were ciliated. They tended to form acini and rounded cystic cavities, which as a whole were much smaller than those shown in Figures 11 and 13. No true basement membrane was present. Many epithelial cells were found lying in the stroma, which between the smaller cysts appeared very cellular as a whole, but the infiltration with epithelial elements frequently overshadowed the true stromal architecture. Scattered throughout the stroma were small groups of nonstriated muscle fibers.

In Figure 14 is seen the most rapidly growing, from a histologic point of view, of all the growths encountered in this investigation. It was located in a mass of fat in the right mesosalpinx, which was firmly adherent to the right posterior surface of the fundus uteri. While the term "adenoma" has purposely been avoided in the anatomic descriptions thus far, I cannot help remarking that the term "papillary cyst-adenoma" conveys better than any other one expression the essential features of this growth. There were numerous cystic cavities into which projected papillary processes of many sizes and shapes, from very simple to complex arborizations. These processes were covered with cuboidal to columnar epithelium, frequently stratified. The cells were deeply staining with a large round to oval nucleus, which occupied most of the cell and as sometimes in mitosis. Ciliated cells were very numerous both on the cells



lining the smaller acini and on those lining the largest spaces. The stroma was very cellular in the more rapidly growing parts, but elsewhere it contained much collagen and endothelial lined spaces. A few lymphoid cells were found scattered here and there in the more cellular areas.

Many epithelial buds and dilated acini were present in the tissue underlying the lining membrane, apparently arising from the latter. Smaller cystic outgrowths had proceeded toward the fundus uteri, which, while not actually experiencing invasion of its muscle wall, nevertheless was greatly distorted by a papillary cystic growth where it was attached to the mesosalpinx. Serial sections were made of the whole of this growth. Smooth muscle was present in small amount in the stroma. The reaction about the entire mass was quite

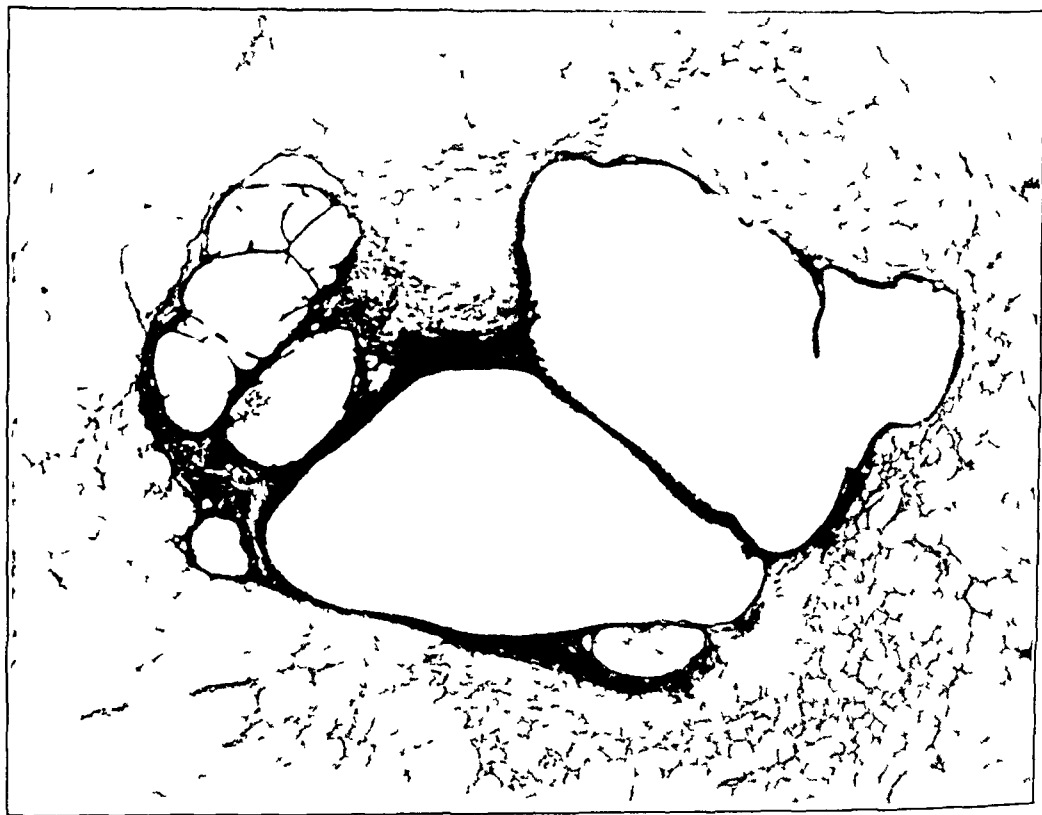


Fig 11—Low power photomicrograph of a multilocular cyst in the right mesosalpinx of Rabbit 4

similar to that which had occurred about the growths in the animals previously mentioned.

The epithelial reaction in Figure 14 was very similar to that which had occurred in the cornu which contained the fetuses, but it was distinctly different from that in Figures 11 and 13, as the photomicrographs show.

EXPERIMENT 5—At operation on Rabbit 5, pregnancy was found, there being five fetuses of about midterm in each cornu. A linear incision was made in the anterior wall of the left cornu, over the fetus lying proximal to the fundus uteri. The membranes bulged into the defect, but there was little bleeding. Nothing further was done and the animal was allowed to recover. Twenty-four days later, the animal was killed with ether.

At necropsy no gross evidence was found of the incision in the left cornu. It had apparently healed completely without a scar. Three indurated areas were found in the fat of the mesosalpinx of each side. They were all in a triangular area, about 3 cm wide, whose base was the upper surface of the left cornu. Two of these indurations were 3 mm in size, the other, 1 mm. The ovaries contained many distended follicles and corpora lutea.

*Histologic Examination*—In the mesosalpinx of the left cornu was a cyst, about 8 mm in diameter. It was lined with flattened or cuboidal epithelial

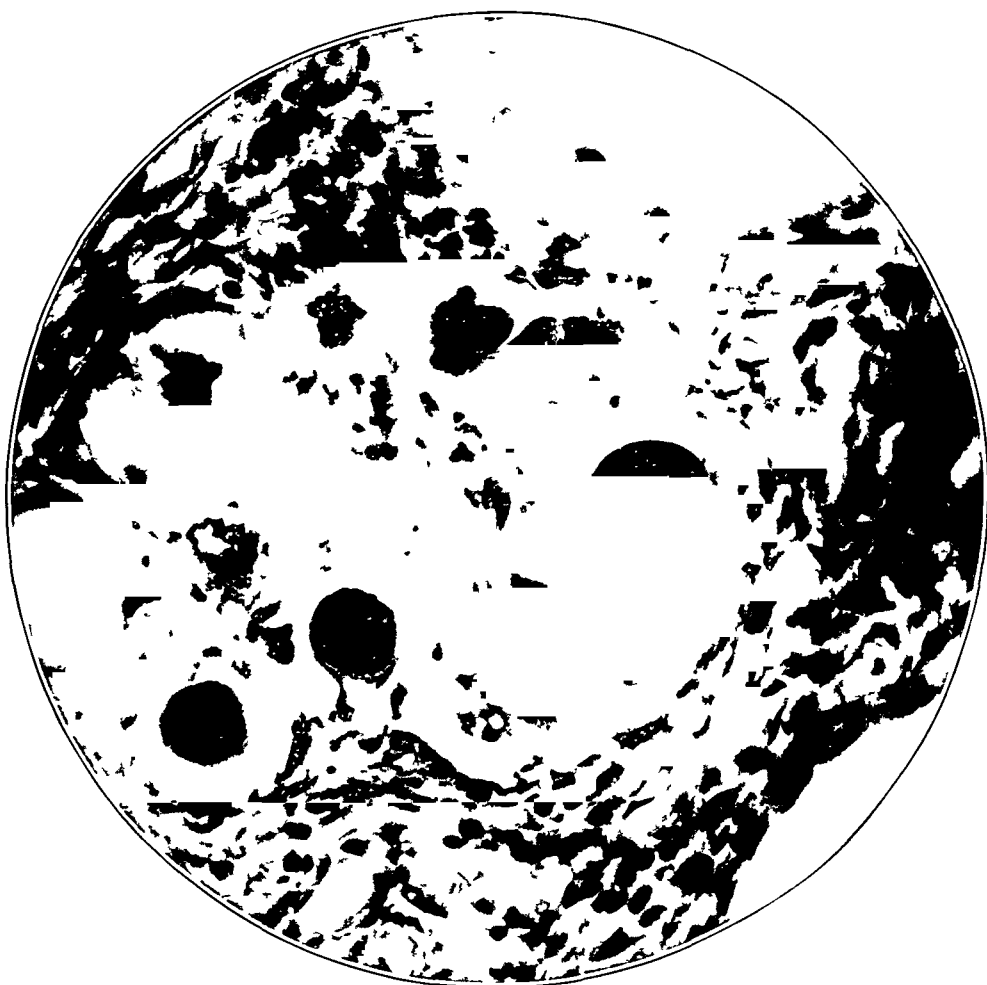


Fig 12—Epithelial proliferation in the stroma of the cyst in Figure 11, showing a tendency to form syncytial-like masses about dilated spaces

cells, many of which were densely ciliated. The nuclei were round or oval, with their long axes parallel with the circumference of the cyst. In the lumen was a fine granular precipitate. Beneath the epithelial layer was a compact layer of collagen, fibroblasts and a few smooth muscle fibers. The cyst was in contact with the peritoneum over about one fourth of its circumference. In the surrounding fat immediately adjacent to the cyst there was slight fibroplastic activity and a few small groups of smooth muscle fibers lay isolated.

In another place in the fat was an epithelial lined cyst about 2 mm in diameter. The cyst communicated with a smaller cyst which was probably the

result of an outgrowth from the larger. In the lumen of both were a few degenerating epithelial cells and mononuclear phagocytes containing pyknotic material and fat droplets. An occasional cell lining the larger cyst was provided with cilia. The lining was composed of epithelium which in places consisted of several cells in strata. They were cuboidal to low columnar but of much irregularity in outline. No mitotic figures were seen. About the epithelial

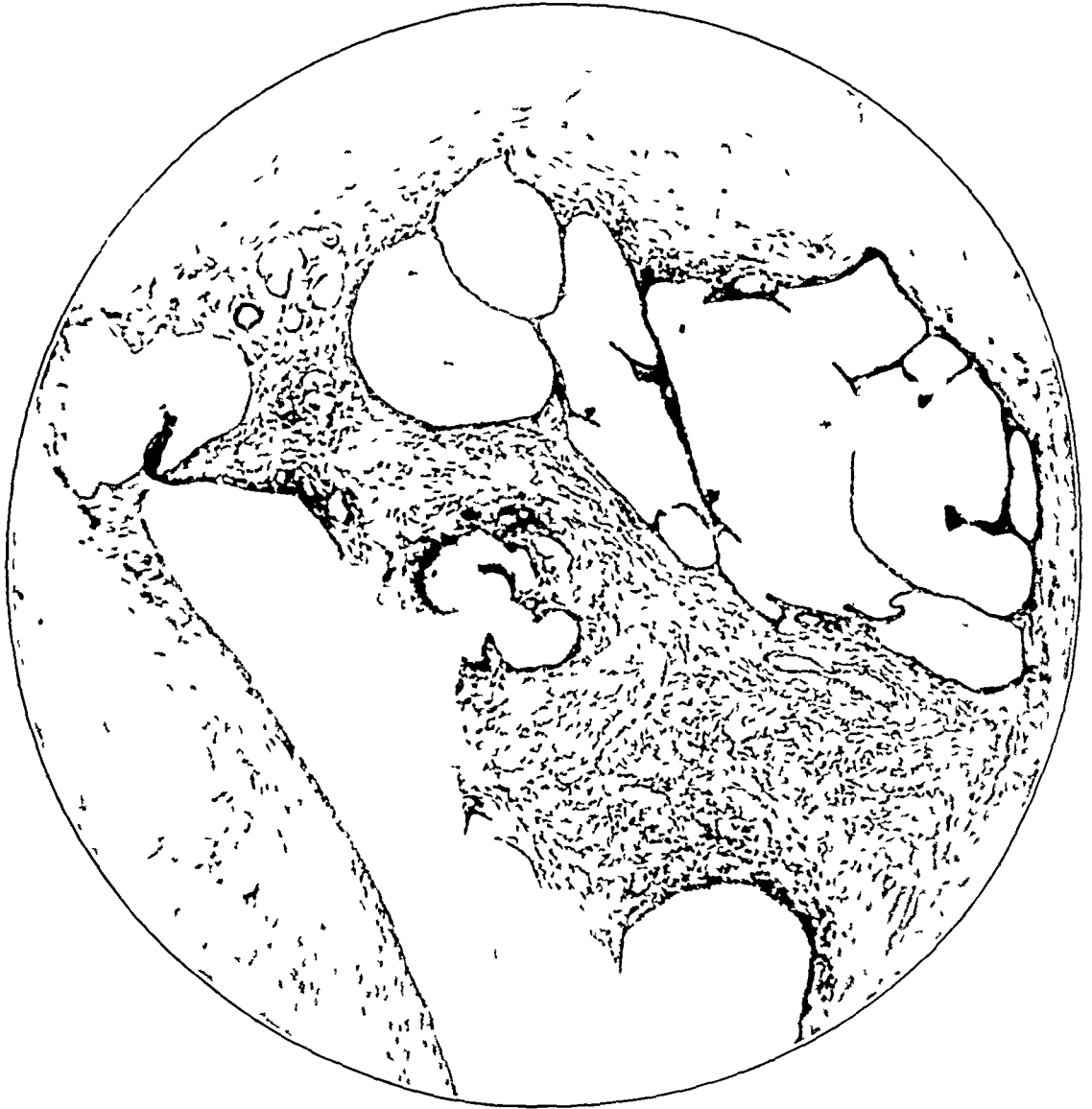


Fig 13—Low power photomicrograph of a multilocular cyst in Rabbit 4, showing epithelial proliferation in the stroma and the characteristic reaction in the surrounding fat about an endometrial autotransplant

layer was a condensation of collagen, fibroblasts and a moderate number of nonstriated muscle fibers. In the adjacent fat was much hemorrhage, fibroplasia, infiltration by eosinophils and mononuclear phagocytes. Many newly formed capillaries were present. This cystic growth was apparently very young and the reaction about it was more intense than in the usual autotransplant.

The cornua showed the same picture as in Rabbits 1, 2 and 3.

## COMMENT

In attempting to plant tissue in the peritoneal cavity of a rabbit, certain difficulties are encountered. Peristalsis of the intestines and uterine cornua dislodge transplants unless they are firmly placed. The endometrial tissue will grow where it stays "put," and if it is cast from its anchorage repeatedly, it probably dies and is disposed of as a foreign body. Injury to the peritoneum probably assists in the localization of the transplants, and this is in accord with Sampson's theory of a possible faculty of menstrual blood to prepare the peritoneum for the growth of cells escaping from a perforating hemorrhagic cyst of the ovary. In



Fig 14—Low power photomicrograph of the very rapidly growing 'papillary cyst adenoma' in Rabbit 4. Serial sections show much pressure atrophy of the fundus uteri where the growth encroaches on it.

the rabbit, advantage was taken of the large amount of adipose tissue in the mesosalpinges, and endometrial tissue was embedded deep in it. This method resulted in a large percentage of "takes." The other transplants, after roaming about in the pelvis, settled down and grew in the vesico-uterine space, in the culdesac and on the free serosal surface of the cornua.

In this series of experiments, performed on five consecutive female rabbits, certain facts were demonstrated. (1) Endometrium alone from a nonpregnant animal will grow when transplanted into the fat of the mesosalpinx or on the pelvic peritoneum of the same animal and

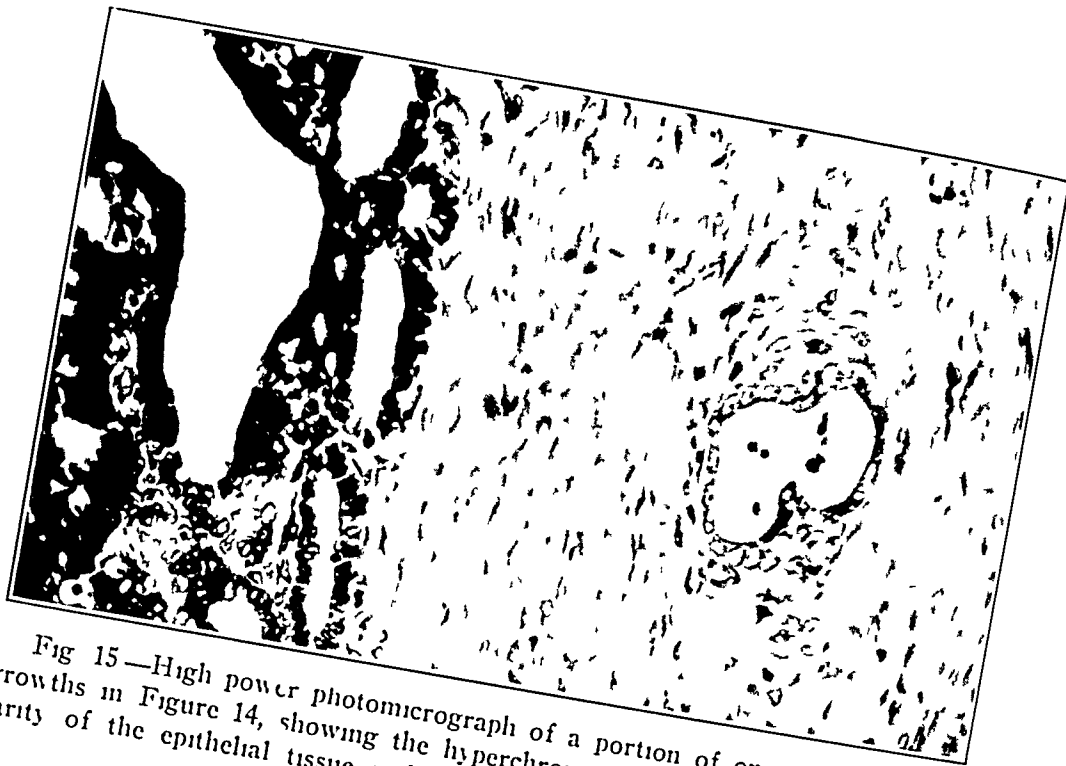


Fig 15—High power photomicrograph of a portion of one of the papillary growths in Figure 14, showing the hyperchromatic epithelium, the great cellularity of the epithelial tissue and invasion of the stroma

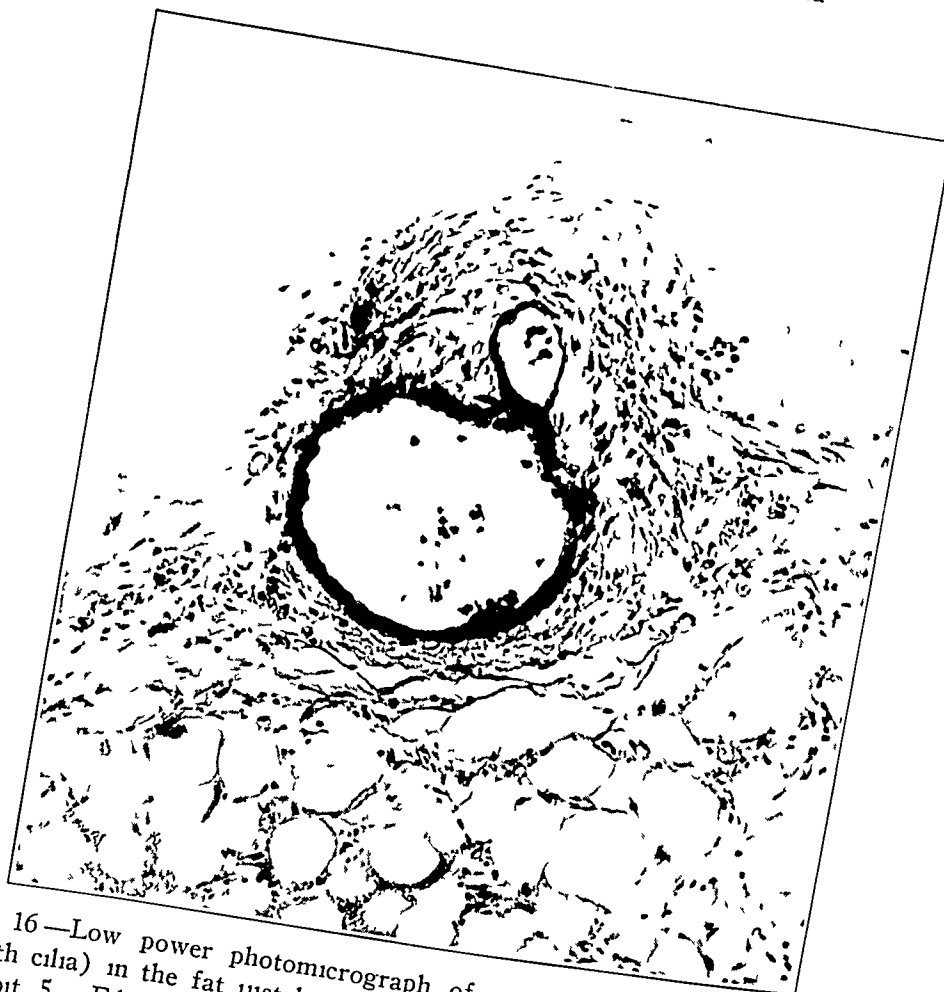


Fig 16—Low power photomicrograph of a growth of epithelium (some cells with cilia) in the fat just beneath the peritoneum of the left mesosalpinx of Rabbit 5. Fibroplasia, hemorrhage, and increased vascularity are to be noted about this epithelium

is found actively growing from fifty-six to seventy days after transplantation (Rabbits 1 and 3) (2) Endometrium from a nonpregnant rabbit will grow when transplanted into an ovary of the same animal, and is found growing sixty-four days after transplantation (Rabbit 2) (3) Endometrium from a pregnant rabbit after transplantation into pelvic fat or onto pelvic peritoneum will grow and show more active proliferative changes than endometrium from nonpregnant rabbits (Rabbit 4) (4) An incision through a cornual segment containing a fetus may result in dissemination of endometrial cells in the surrounding tissues, implantation "adenomas" thus arising (Rabbit 5)

In all of the rabbits, the general type of growth produced, whether in the nonpregnant or in the pregnant animal, was a cyst, usually multilocular. The fluid contents of the cyst were not examined chemically. Since the transplanted tissue acts for a time as a foreign body, the fibrous tissue formation about it, along with smooth muscle fibers, constitutes the capsule into which the epithelial sprouts may grow. The cysts were lined with epithelium which was either actually or potentially ciliated. The stroma may simulate closely that of the cornu of the uterus from which the transplant was made. In Rabbit 1 smooth muscle was abundant about some epithelial growths and much less in amount about others. It seems likely that the former growths arose from transplanted bits of the entire wall of the cornu, the latter from transplanted endometrium. The smooth muscle reaction about endometrial tissue seems foreordained, and some interesting questions arise concerning this feature. Of course, in the transplants of the entire wall, plenty of smooth muscle is included to form a source of future muscle production. In the dissected mucosa, it is practically impossible to leave behind all smooth muscle, as blood vessels are torn in disengaging the mucosa, and the smooth muscle in their walls may be a source of muscle formation.

Just what interpretation can be made of the smooth muscle response about the transplants in these rabbits? The whole question of "adenomyoma" seems to hinge on this special influence of endometrial tissue over smooth muscle in its vicinity. Cuthbert Lockyer, in his "Fibroids and Allied Tumors" page 375, makes the following statement on this subject:

The basis of an adenomyoma is the epithelial heterotopy or invasion. The myomatous constituent is there because the epithelial infiltration has taken place in the structure containing muscle. Muscular tissue is not essential to the process. Epithelium will infiltrate any soft tissue during the process of repair. Under certain conditions this "process of repair" runs riot and a branching glandular growth is produced, if muscle is in the matrix in which this takes place the result is an adenomyoma. If the invaded tissue be solely fibrous the

resultant is a fibro-adenoma, but the underlying genetic factor is one and the same in each case, i. e., epithelial repair (following an inflammatory injury) carried to an excess which becomes pathological

The amount and type of tissue reaction about the transplants otherwise is that usually obtained in autotransplants of the uterus of the guinea-pig into the ear and into the abdominal wall, also in autotransplants of other organs<sup>2</sup>

The most striking characteristic of the multilocular cysts formed in Rabbits 1, 3 and 5 is the similarity in the proportions of the various tissue constituents to the multilocular cyst-adenoma of women. The chief difference is in size. It is well known that ovarian cysts in women are very slowly growing. What would have been the ultimate size of the cysts in these rabbits can only be surmised, but there are no indications that they had reached their maximal development.

Pregnancy appears to exert a profound influence over the autotransplants if Rabbit 4 may be used as an illustration. The tissue transplanted was taken not from the wall surrounding a fetus but from that narrow zone of the cornu on both sides of a fetus. The epithelium there was deeply staining, the nuclei hypertrophied and hyperchromatic, the cells proliferating and sending numerous buds into the submucosa. In this rabbit, two multilocular cysts, much like those of Rabbits 1, 3 and 5, resulted from the transplants, one of them being nearly 2 cm in size. However, a third cyst, while multilocular, was lined with epithelium of the type of the uterine cornu. The stroma also resembled the endometrial stroma. The cysts were small and more numerous, many were more like dilated acini. The cyst in Figure 13 appears to be of a very rapidly growing and invasive type, one which might be called a papillary cyst-adenoma, with some of the characters of malignancy in its epithelial elements, i. e., nuclear and cytoplasmic hyperchromatism, mitosis, invasion of stroma, a tendency toward invasion of structures to which it is adherent (fundus uteri).

That termination of the pregnancy would have resulted in the assuming of a quiescent state by the new growth (transplant) cannot be denied or affirmed at present. The work of Loeb<sup>3</sup> on deciduoma in guinea-pigs suggests such an influence. Studies are being made to determine this point. It does not seem an unreasonable hypothesis that without the influence of pregnancy simple multilocular cysts are usually

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2 Hesselberg, Cora, Kerwin, William, and Loeb, Leo. Auto and Homotransplantation of the Uterus in the Guinea-Pig, *J. Med. Research* **38** 11 (March) 1918.

3 Loeb, Leo. The Production of Deciduomata, *J. A. M. A.* **50** 1897 (June 6) 1908.

formed and that repeated pregnancies in an organism harboring ectopic growths of endometrial origin might cause a summation of growth stimuli with ultimately a malignant metamorphosis

In Rabbit 2 the transplantation into the right ovary of endometrial tissue resulted in the formation of two macroscopic cysts lined with ciliated epithelium. About these cysts was a condensation of collagen fibroblasts and smooth muscle fibers. A small amount of recent hemorrhage had occurred into the lumen and there was some phagocytosis of hemosiderin. In the ovarian stroma were several large deposits of hemosiderin. It is possible, although doubtful, that this is an indication of menstrual reaction. The rabbit, however, is not the proper animal for the study of the effect of menstruation on these cysts. The monkey offers more favorable circumstances for observations involving this phenomenon.

Polypoid ingrowths of the lining epithelium were present in each cyst. With the exception of the difference in size, these cysts have much the same structure as the larger "ovarian" cystadenoma of women. A sudden hemorrhage into one of these cysts might cause its rupture, with the liberation of epithelial cells and blood into the pelvic cavity, and it would be surprising, indeed, in the light of Sampson's clinical and pathologic observations on patients with perforating hemorrhagic cysts of the ovary, if implantations did not result.

#### CONCLUSIONS

It has been demonstrated in this series of experiments that endometrial tissue transplanted into the ovary and pelvic fat of the same animal will grow for as long as seventy days and probably much longer. Adenoma-like growths and multilocular cysts, which, histologically, show much similarity to "ovarian" cyst-adenomas of women, are produced. Under the influence of pregnancy, a more rapid epithelial growth occurs, with the production of a papillary "cyst-adenoma" which has some of the characteristics of a malignant growth. All of these observations are in agreement with Sampson's explanation of adenomas of endometrial type which are found in the ovary, in the culdesac, adherent to and invading the appendix, intestine, rectum, oviduct and uterus, and which apparently arise from ectopic epithelium discharged into the pelvis through the fimbriated end of the oviduct, this epithelium coming either from the uterus or the oviduct or from both.<sup>4</sup>

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<sup>4</sup> Sampson J. A. Ovarian Hematomas of Endometrial Type (Perforating Hemorrhagic Cysts of the Ovary) and Implantation Adenomas of Endometrial Type, Boston M. & S. J. 186:445 (April 6) 1922.



It is difficult to define a tumor, and if these growths in the rabbit cannot be so classified, they might constitute a phase between tumor and nontumor. If further researches confirm the findings in this small series of animals, it would seem that Ribbert's hypothesis will have been given a sort of half demonstration, namely, that simple misplacement of mature endometrial epithelial cells is conducive to their neoplastic transformation.

An incision through the entire thickness of the wall of a cornual segment containing a fetus is sufficient to cause the escape of mucosal epithelium from the cornu into the pelvis and from these ectopic epithelial cells implantation "adenomas" develop.

There seems a strong likelihood that the origin of pseudomucinous cyst-adenomas and papillary cyst-adenomas will be explainable on the basis of their arising from ectopic endometrial tissue. Also that pregnancy may, perhaps, exert an influence on these growths in the direction of malignant degeneration.

# DIRECT TRANSFUSION OF BLOOD

## REPORT OF CASES \*

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AND

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The ease with which blood transfusion by the citrate method may be carried out has, during the last ten years, resulted in its use, almost to the exclusion of direct methods. It has popularized transfusion in various diseases, and has, without doubt, in the aggregate been most beneficial. More patients requiring transfusion have been transfused than before the development of the indirect method, and there can be no question that a large number of lives have been saved by its employment. The general statistical results are good. It is in a consideration of the results in individual cases that certain dangers in citrate transfusion become apparent.

### REACTIONS FOLLOWING CITRATE TRANSFUSION

Considerable literature has accumulated during the last few months concerning the types of reaction following citrate transfusion, and the causes therefor. P W Clough and M C Clough<sup>1</sup> have given an excellent summary of the three types of reaction: the first, occurring in persons apparently of homologous blood groups, and in whom the reaction must perforce be due to some alteration of the blood during the process of transfusion, the second, or so-called hemolytic reaction following the use of incompatible blood, and the third, occurring in persons who have received many transfusions and in whom there has apparently developed some alteration that renders them sensitized against the blood of the donor.

With the two latter types of reaction we are not immediately concerned. The third type may occur either after a direct or indirect transfusion, and the second can usually be avoided by appropriate methods of matching. It has been found, however, that much more careful matching is necessary than has hitherto been employed. Both direct matching and blood grouping should be done, and examination for agglutinative phenomena should be made, covering a period of many hours instead of the one hour generally allowed.

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\*From the surgical, medical and urologic services of St Elizabeth's Hospital

1 Clough, P W , and Clough, M C. Southern M J **14** 104 (Feb ) 1921

Numerous explanations for the first type of reaction have been offered. After eliminating variations or errors in technic by the use of freshly distilled water, chemically pure reagents, aged or specially treated rubber tubing, constant temperature, and a minimum time, reactions of this type still occur, and, as has been stated, appear to be due to some alteration in the blood itself, dependent on its treatment.

Drinker and Brittingham<sup>2</sup> have demonstrated changes in the blood platelets coincident with early coagulation. Many of them are partially

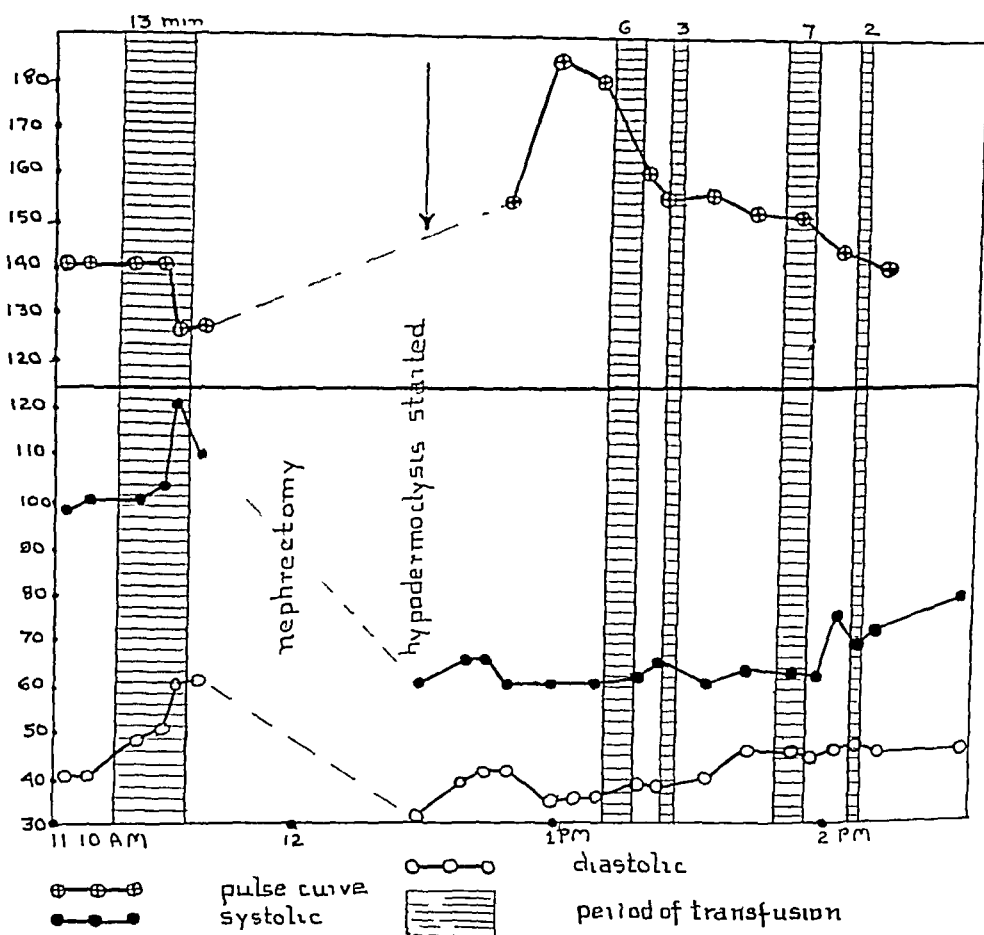


Chart 1—Pulse and blood pressure curves in a case with profuse hemorrhage from the left kidney. The patient was in shock before operation, and transfusion raised the blood pressure and lowered the pulse. During operation, more severe shock developed, and a second transfusion was given with satisfactory results as regards pulse, blood pressure and general condition. The shaded areas denote periods of transfusion. The second transfusion was discontinued because of reaction in the donor (compare Chart 5). The symbols explained under this chart are used in all the other charts.

2 Drinker, C. K., and Brittingham, H. H. Transfusion Reactions, *Arch Int Med* 23: 133 (Feb) 1919.

or totally destroyed in citrate transfusion. They have also shown that the addition of sodium citrate in the amounts used in transfusion increases the fragility of the red blood cells, and the tendency to hemolysis.

Unger<sup>3</sup> has shown that the addition of sodium citrate in the proportion used in transfusion to normal blood renders it anticomplementary in the Wassermann reaction. He concludes, in a brief report of his experiments, that in citrate transfusion blood is being given in

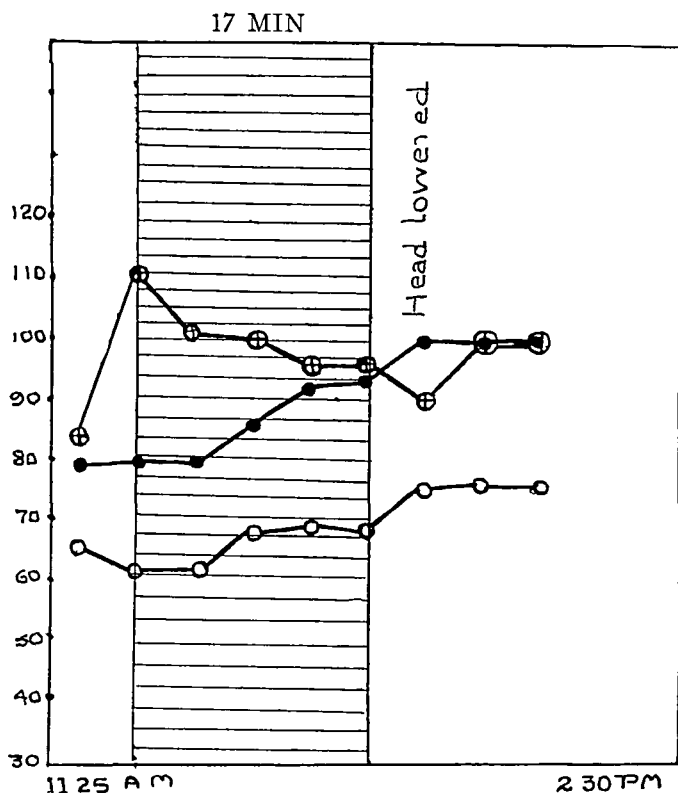


Chart 2—Rapid rise in systolic and diastolic blood pressure, with diminution of the pulse rate during and following the period of transfusion. This is the type of curve most frequently encountered.

which complement has been diminished in two ways: first, by the production of an anticomplementary substance which inactivates some of the available complement, and second, by direct partial destruction of the normal complement in the serum. He believes that he has shown that this action of sodium citrate is directed in part at least against the red cells themselves, and that it persists even after the hemoglobin

3 Unger, L. J. Deleterious Effect of Sodium Citrate Employed in Blood Transfusion, *J. A. M. A.* **77** 2107 (Dec. 31) 1921.

has been removed from them. He has also demonstrated a diminution in the phagocytic power of the leukocytes and in the opsonic power of serum, after treatment with sodium citrate.

Henderson and Haggard<sup>4</sup> report that after bleeding a dog to a point previously determined, at which the chances for recovery or fatal issue are about equal, the injection of even a small amount of sodium

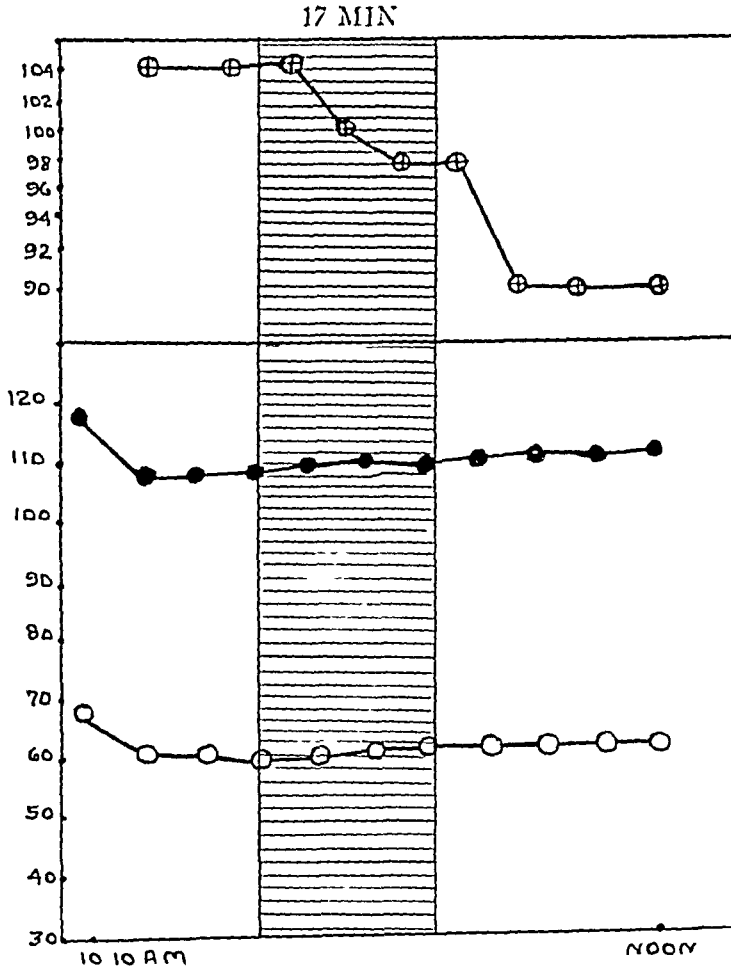


Chart 3—Transfusion administered as a prophylactic measure before the advent of actual shock. Good results are evident chiefly in the pulse curve.

citrate into the veins will cause almost immediate death. This fact is surprising when contrasted with the reports of other observers<sup>5</sup> regarding the beneficial action of sodium citrate injected intravenously in the treatment of hemorrhage. Further work will probably clarify this problem.

<sup>4</sup> Henderson, Yandell, and Haggard, H. W. Hemorrhage as a Form of Asphyxia, *J. A. M. A.* **78** 697 (March 11) 1922.

<sup>5</sup> Neuhof, H., and Hirshfeld, S. *New York M. J.* **113** 95 (Jan. 15) 1921.

It is an evident fact, therefore, that citrated blood, as used in transfusion, is a changed blood, and that the changes so far studied are of a deleterious nature. Citrate transfusion at best is but a makeshift method. There has never been any question, even among the most ardent advocates of the indirect method, as to the advantages of direct transfusion when practicable, and it is only because of the relative difficulty and inconvenience of performing direct transfusion that the indirect method has attained such great favor.

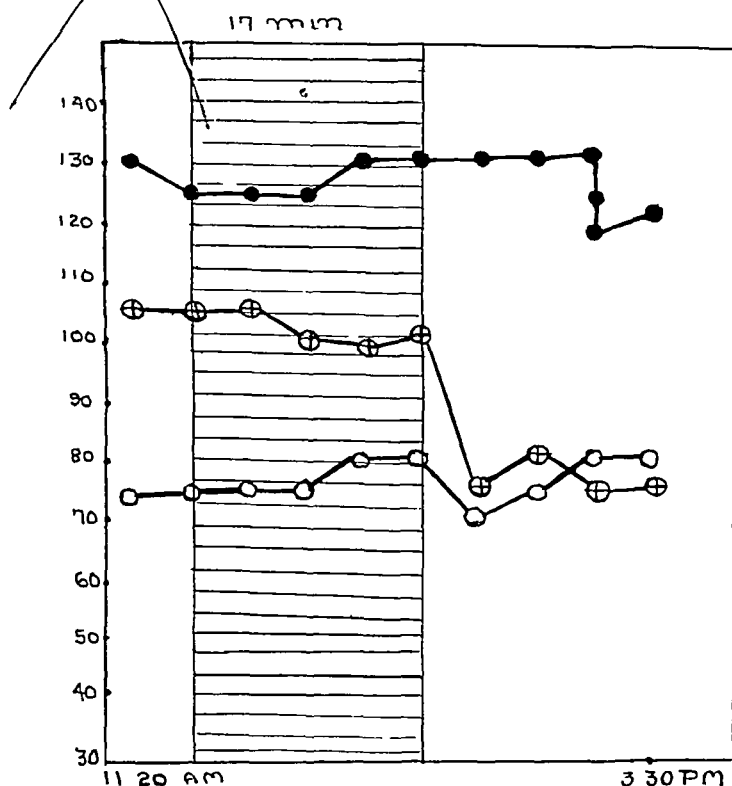


Chart 4—Type of pulse and blood pressure curves most frequently encountered in donors. The blood pressure remains practically unchanged. The pulse, which is moderately accelerated because of excitement and apprehension, later falls to normal.

#### RELATIVE VALUE OF WHOLE AND CITRATED BLOOD TRANSFUSIONS

If the employment of whole unchanged blood could be made as simple as the use of citrated blood, there is no doubt that the former method would be universally employed. As has been emphasized by Bernheim<sup>6</sup> and others, it is in the localities where there is no expert trained in the employment of direct transfusion that the indirect method

6 Bernheim, B. M. Whole Blood Transfusion and Citrated Blood Transfusion, Possible Differentiation of Cases, *J. A. M. A.* **77**:275 (July 23) 1921.

has, and will have, a distinct place and value, but when direct transfusion can be employed equally efficaciously, we believe that it should be the method of choice

The outstanding advantage of whole blood transfusion over citrate transfusion lies in the decidedly lessened incidence of post-transfusion reactions of the first type described by Clough and Clough. By the citrate method the frequency of reactions is variously estimated from 17 per cent to 60 per cent—averaging around 32 per cent. In whole blood transfusions, Bernheim found reactions to be present in 5 per

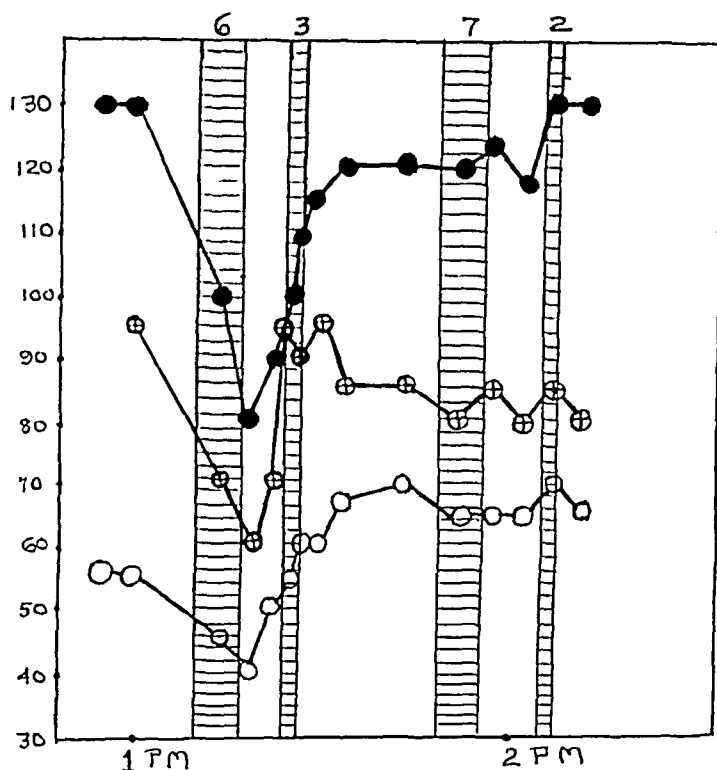


Chart 5—"Vagus" type of reaction in donor, with early fall of pulse rate and blood pressure

cent, Sloan in 5 per cent, and Lewisohn in 5 per cent. A few observers have found differing results, such, for instance, as those of Ravdin and Glenn,<sup>7</sup> who found about equal incidence of reactions following both citrate and whole blood transfusion. However, the weight of evidence given by the various observers who have had wide experience in both methods unquestionably favors the incidence of a very low percentage of reactions following direct transfusion, and a high percentage following the indirect method.

<sup>7</sup> Ravdin, I. S., and Glenn, E. *Am J M Sc* **161** 705 (May) 1921

Disagreements regarding direct transfusion are, to some extent, at least, to be accounted for by differences in operative technic. Certain methods of so-called direct transfusion, as, for example, by the use of multiple syringes, are in a sense indirect methods. There are grades of directness, and it has been our experience that the more nearly direct the method, the less liability is there of reaction occurring.

Our experience during the last eighteen months has been mainly with surgical cases, complicated by shock or hemorrhage, or both—cases in which the occurrence of a reaction, with chill, fever, nausea,

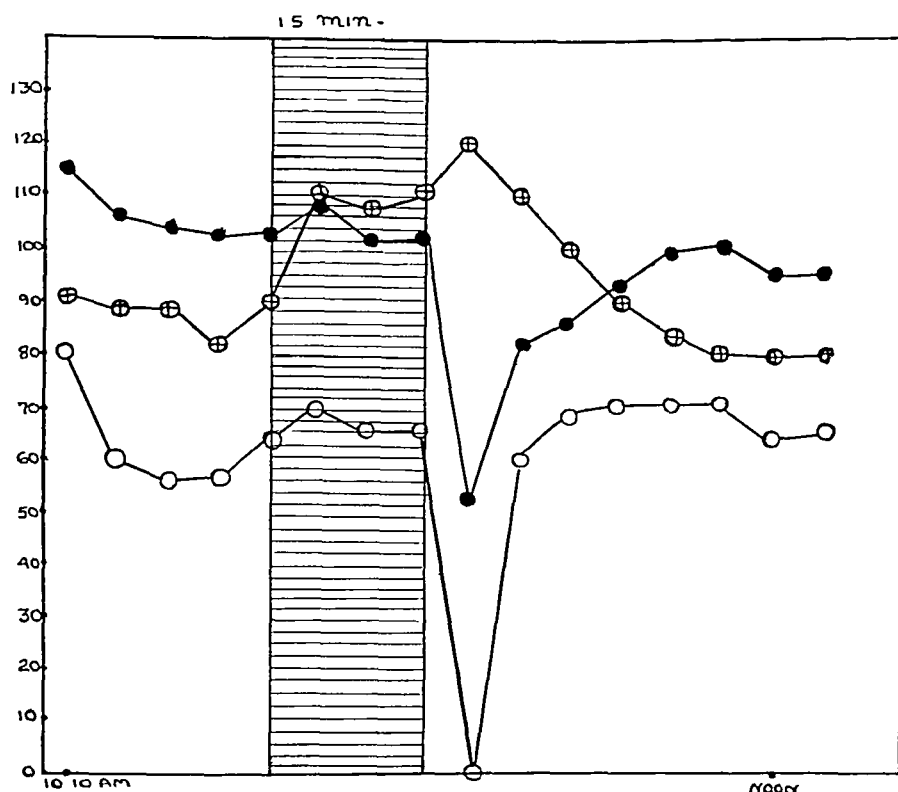


Chart 6—Late type of reaction in donor, with fall in blood pressure and increase in pulse rate

vomiting, and so forth might easily be the deciding factor in the balance between life and death, and we have, therefore, had an excellent opportunity to study the advantages and disadvantages of the direct method of transfusion. We were led to return to the direct method through apprehension that the occurrence of a severe citrate reaction might sooner or later result in an unwelcome fatal issue. We had had no deaths attributable to the use of sodium citrate in indirect transfusion, but had witnessed some disquieting reactions. We had one death with symptoms of hemolysis following this method, though the bloods had been previously matched. A certain number of deaths have been described in the literature.



The characteristic reaction following citrate transfusion usually commences with a chill, coming on from one to two hours after transfusion, and followed by a rise of temperature of from 2 to 6 degrees. The maximum fever is usually reached within from two to four hours, and the return to normal occurs a little less rapidly than the development of the fever. Occasionally, the fever may persist for as long as three days. The subjective symptoms consist of chilliness, headache, general discomfort, and, occasionally, nausea and vomiting. Both the pulse and respiration are somewhat accelerated. As a rule, recovery is rapid and, to all appearances, complete. There is no way in which one may tell in what case one may expect a serious reaction with a high fever of long duration, or a mild reaction, or none at all.

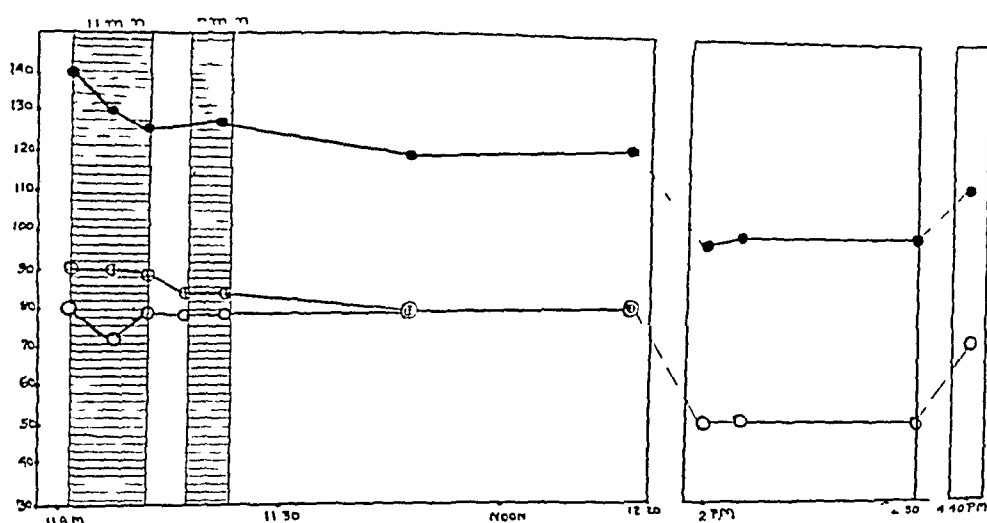


Chart 7—Delayed reaction in donor coming on two and one-half hours after the termination of transfusion, and due chiefly to depletion

During the last eighteen months we have performed twenty-four direct transfusions. In no case has there been a distinct reaction to the transfusion. One patient (Case 6503), whose case was diagnosed metrorrhagia, hypertrophy of the uterus, sclerosis of the uterine vessels and cyst of the right ovary, had been bleeding profusely over a long period of time, so that the hemoglobin had fallen to 44 per cent, red count to 1,904,000. A hysterectomy was performed, with the removal of a cystic ovary. Immediately after the operation she was transfused by the direct method (Chart 3). The patient belonged to Group II, and the donor to Group IV. Following transfusion she complained of a low-grade pain in the back and abdomen, and for several days thereafter she had mild diffuse joint pains. She vomited only once after the general anesthetic and transfusion. Two or three days after the operation, she developed herpes on the lower lip. The temperature

after operation at no time rose above what it had been during the preceding three days (102 F), and there was no respiratory distress and no hematuria. The backache frequently occurs after hysterectomy, and the patient had given a previous history of recurrent general joint pains. Thus, even though the donor and recipient were of different blood groups, one is scarcely justified in calling this case a definite transfusion reaction.

This case is reported in some detail because it comes nearest to being a case of transfusion reaction of all of our twenty-four cases.

Most of the transfusions have been performed on patients at the time of operation, and the presence of a low-grade febrile reaction cannot be taken as evidence of transfusion reaction, unless accompanied by other distinctive signs. In none has chill occurred, and in none has there been any nausea, vomiting, respiratory distress, urticaria, or other symptom than that usually found in similar postoperative cases. It is customary, in discussing transfusion, not to consider an increase of 1 or 2 degrees of temperature, with entire absence of other manifestations, as evidence of reaction.<sup>7</sup>

#### TECHNIC OF DIRECT TRANSFUSION

The method of transfusion used in the twenty-four cases we report is the direct method by the cannula. The cannula used is the one devised by Bernheim, and is made of silver. It consists of two parts, a male and a female part, one fitting accurately into the other. The ends of each half terminate obliquely, to facilitate inserting them into the vessels. The end of the male half is for the donor's artery, and is slightly smaller than the end of the female half, which is for the recipient's vein. The two halves are disconnected and boiled in a good mineral oil.

The region over the lower end of the left radial artery of the donor is well infiltrated with 0.5 per cent procain solution, to each ounce of which about 2 drops of from 1 to 1,000 solution of epinephrin has been added. After about three minutes, an incision  $1\frac{1}{2}$  inches (3.8 cm.) long is made over the radial artery, and the artery is carefully dissected out. Care is taken to clamp every bleeding point with mosquito forceps. About three-fourths inch (19 mm.) of the artery is exposed. After first exposing the artery, the dissection may be more quickly completed bluntly by spreading closed scissors. Mosquito forceps are used to catch about one third of the lumen of the artery near its lower end, and a fine catgut ligature is passed beneath the artery and tied, while gentle traction is made upward and toward the body with mosquito forceps. In this way the ligature is placed at the extreme distal end of the exposed artery. All bleeding points are tied with fine silk or fine catgut. A serrefine is placed on the artery at the upper end leaving a little more

than a half inch (1.2 cm) of the artery between the ligature and the serrefine. The mosquito forceps, which still grasp the artery, are lifted up, and an oblique incision is made into the artery about one-third or one-half through its caliber. Through this incision, the male half of the cannula, which has been boiled in mineral oil, is passed. If there is any difficulty about introducing it, closed mosquito forceps can be inserted to dilate the artery. After inserting the cannula, it is tied snugly with a small linen ligature.

The wound is covered with moist gauze, and the female half is inserted into a vein of the patient in a similar manner. It is advisable to use a vein that is sufficiently large, but not necessarily the large veins at the flexure of the elbow, as the scar here may later cause inconvenience.

The male half of the cannula may be inserted, with the donor in the operating room, and he may be permitted to walk to the patient's room and recline in an easy chair while the two halves of the cannula are connected. Just before connecting the cannula, a small spurt of blood from the radial artery is allowed to flow in order to expel the air. The female half may be filled with salt solution for the same purpose. The two halves of the cannula are then quickly united, both serrefines are removed, and the current of arterial blood is turned on. The pulsation can be felt, and usually can be seen, in the vein. If there is a tendency to clot, the serrefine is replaced on the artery, and the two halves of the cannula are disconnected. A clot may be removed by applying suction from a syringe fitted with a small rubber tube, such as a piece of a small catheter. If this does not succeed, a silver probe is introduced into the cannula at either end, and the serrefine on the artery is removed until the blood flows freely. Occasionally, clotting occurs very rapidly, so it is well to have two cannulas ready, that a new one may be inserted if the first one clots too frequently. Usually a strong flow is obtained, which will last for ten or fifteen minutes without interruption. Occasionally, it is necessary to disconnect the cannula and clean it out.

It is important to see that the cannula is clean, that it is coated with oil, and that no blood is permitted to come in contact with its interior until immediately before the two halves are connected.

The linen ligature should be removed before closing the wound, otherwise it may cause trouble later. The vessel is ligated with fine plain catgut, and the wound closed in the usual way.

It is true that in the direct cannula method we do not know the amount of blood transfused. This is a valid criticism of the method, but we would point out that the important element in transfusion is not the administration of 500 cc or 1,000 cc, or any stated amount of blood, but the infusion of sufficient blood to produce the desired

therapeutic effects In the administration of ether, or any drug, the object is not to give a definite amount, but to obtain a therapeutic effect

It is very important when using this method that the condition of both the recipient and the donor be followed first, to ascertain when a sufficient amount of blood has been transfused, and second, to prevent excessive depletion of the donor We have had no trouble in any of the transfusions with regard to the second factor The routine followed at St Elizabeth's consists in recording at two and one-half or five minute intervals the systolic and diastolic blood pressure and pulse rate of both donor and recipient, together with close observation of the general condition and subjective symptoms in both persons It has been our experience in several cases of shock immediately following operation that the systolic blood pressure will fall to as low as 80 or 70 mm, and the subsequent rise following transfusion is rapid and satisfactory, as indicated by the accompanying blood pressure curves for the recipients (Charts 1 and 2) We have found that from fifteen to eighteen minutes of transfusion is sufficient for therapeutic results, and does not cause too much depletion of the donor A great deal depends, however, on the size of the vein used in the recipient, on the size of the artery and on the blood pressure of the donor The process must be carefully watched to prevent the transfer of too large an amount of blood

#### REACTION OF DONOR TO TRANSFUSION

The blood pressure curves in the donor show as interesting changes as do those of the recipient We have found, in general, four types of curves, as illustrated by Charts 4 to 7 In the first type, which comprises the great majority of cases, there is no change in blood pressure throughout the transfusion, or after its completion In the second type, the blood pressure of the donor may fall rapidly at, or near, the onset of transfusion to as low as 80, systolic, or 40, diastolic The fall is rapid over a period of five or ten minutes, and is accompanied by a slowing of the pulse of as much as thirty-five beats per minute, with the development of a sudden intense greenish pallor In this type of case we have terminated the transfusion temporarily until the blood pressure has returned to about normal, after which the transfusion may usually be continued for the customary length of time without further subjective change, or change in the blood pressure or pulse rate This appears to be a *vagus* type of reaction

A somewhat analogous type of reaction consists of a fall, occurring toward the end of transfusion, or immediately after the transfusion has been terminated In one case the systolic pressure fell to 54 and the diastolic could not be obtained One distinct point of difference is that in this type the pulse rate rises The subjective symptoms are

similar, and there may be nausea and vomiting. Lowering of the head and the administration of aromatic spirit of ammonia will usually be sufficient to produce a rapid amelioration of symptoms, and the blood pressure again rises to normal, while the pulse rate falls. It may take as long as forty minutes before normal equilibrium is restored. This reaction appears to be due more to a loss of blood than to psychic factors, and is a danger signal calling for immediate termination of the transfusion.

Another type of reaction in the donor has been observed. Thus, in Chart 7, the donor at the onset of transfusion had a systolic blood pressure of 140, diastolic 80. This fell during transfusion to systolic 125, and diastolic 80, and for one hour after transfusion the pressure remained constantly 120 systolic, diastolic 80. It was not until two and one-half hours after the termination of transfusion, when the donor was allowed to sit up in a chair, that he began to feel faint. The skin became pale, cold and clammy, with a slightly greenish tint, and the patient lost consciousness. The blood pressure at that time was 96 systolic, and 60 diastolic. He was placed in bed, the foot of which was elevated. The systolic blood pressure remained below 100 for more than one-half hour, but gradually increased, and at the end of two and one-half hours it was 110 systolic, 70 diastolic. The patient was allowed to get up, returned home, and had no subsequent symptoms.

Cases with the last three types of reaction are infrequent. The first type of curve is that usually encountered. The factors influencing the type of reaction in the donor appear to be (1) the amount of blood withdrawn, (2) psychic influences, (3) vasomotor instability, (4) the rapidity with which fluid depletion can be replaced by the administration of fluids by mouth, and (5) the time at which the donor is allowed to get up.

#### ILLUSTRATIVE SEVERE CASES

Case 5846 was that of a man, 75 years of age, who was operated on for cancer of the prostate. After a preliminary suprapubic drainage, a suprapubic prostatectomy was performed. Immediately after operation the temperature was normal, the pulse 90, and the respiration 22. Two hours later the patient began to bleed profusely from the site of operation. The condition rapidly became critical. The pulse increased to 160, respiration 24, and the blood pressure fell to 75 systolic, diastolic not obtainable. He was transfused, and the blood pressure steadily increased until at the end of fifteen minutes of transfusion the systolic pressure was 115, diastolic 85. The pulse fell to 120. There was some bleeding for a short time only, following the transfusion. The patient made an uneventful recovery, and is now symptom-free.

eleven months after the operation. If in this case there had been a transfusion reaction, there can be little doubt that the patient would have died.

Another patient (Case 6112) was admitted with bleeding from the left kidney. Fifteen days after a nephrotomy, the patient began to bleed in very large amounts through the wound, and it was found necessary to perform a nephrectomy. Before operation, the hemoglobin was 55 per cent, red count, 2,844,000. The patient was first transfused for thirteen minutes before operation (Chart 1). The pulse was 135, systolic blood pressure 98, diastolic 40. At the end of transfusion, the pulse had fallen to 122, and the blood pressure had increased to 110 systolic, 60 diastolic. A rapid nephrectomy was performed, toward the end of which hypodermoclysis was started. A half hour after completion of the operation, the systolic blood pressure was 60, diastolic 35, and pulse 180. He was transfused a second time from a second donor, for eighteen minutes, after which the pulse fell to 135, and the blood pressure rose to 80 systolic, and 45 diastolic. Hypodermoclysis and supportive therapy were continued in this case, and the patient made an uneventful recovery. Here, too, a typical citrate reaction might have proved fatal.

#### CONCLUSION

We wish to emphasize the fact that in indirect transfusion, and particularly in citrate transfusion, there are chemical and biologic changes in the blood, and it seems probable that the reactions which often follow this method of transfusion are due to these changes. These reactions are sometimes very severe, and occasionally cause death. In the series of twenty-four cases of direct transfusion, which comprise all of the transfusions we have performed during the last eighteen months, there has been no reaction.

# AN EXPERIMENTAL STUDY OF METHODS FOR BRIDGING NERVE DEFECTS

WITH A DESCRIPTION OF A NEW METHOD OF AUTOTRANSPLANT  
(AUTO-AUTOTRANSPLANT)

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ST. LOUIS

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## I INTRODUCTION

In 1918 one of us found that, after removing a tumor of the ulnar nerve, there was such a large gap that it was impossible even by transplanting the nerve into a new bed and flexing the arm to get the two ends together. He, therefore, implanted the central and peripheral ends into longitudinal slits in the median nerve with the idea of using the nerve as a bridge. The nerve regenerated perfectly.

The research herewith reported was undertaken to determine the best method of repairing an injured peripheral nerve when an end-to-end suture was not possible. The advantage of a cable autotransplant as compared with a homotransplant or heterotransplant has been so

completely worked out by Huber<sup>1</sup> and his co-workers that we saw no purpose in repeating their work. We saw certain possible objections, however, to this method which prompted us to investigate other methods for bridging defects in peripheral nerves. Our experiments have been carried on over a period of two years. The cases were studied both anatomically and physiologically.

We will not discuss the literature on this subject. The most important work bearing on this subject has been done by Huber,<sup>2</sup> Howell and Huber,<sup>3</sup> Joyce,<sup>4</sup> Kilvington,<sup>5</sup> Osborne and Kilvington,<sup>6</sup> Kirk and Lewis,<sup>7</sup> Langley and Hashimoto,<sup>8</sup> Ranson,<sup>9</sup> Spiller, Frazier and Van Kaathoven,<sup>10</sup> and Von Hofmeister.<sup>11</sup>

## II METHODS USED IN THIS RESEARCH

1 *Technic*—Dogs were used for all the experiments. The animals were always operated on under general anesthesia. In each case the sciatic nerve and its branches were used. Care was taken to have a bloodless field, to handle the nerves as little as possible and then only by the perineural sheath. The nerves were cut with a razor blade and handled with fine mouse tooth forceps. The sutures throughout were of silk, either blood vessel silk or one strand of split No. 10 silk, threaded on a No. 10 cambric needle. The sutures were passed only through the perineural sheath. Bleeding from the cut end of the nerve

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7 Kirk, E. G. and Lewis, Dean. Regeneration in Peripheral Nerves, *Bull. Johns Hopkins Hosp.* **28** 71 (Feb.) 1917.

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10 Spiller, W. G., Frazier, C. H. and Van Kaathoven, J. J. A. Nerve Transplantation in Treatment of Cerebral, Spinal and Peripheral Nerve Palsies, *Am. J. Med. Sc.* **131** 430 1906.

11 Von Hofmeister. Ueber doppelte und mehrfache Nervenprotopung. *Beitr. z. klin. Chir.* **96** 329, 1915.



was controlled either by cotton pledgets soaked in warm saline or by the injection of warm saline into the nerve. Nerve tissue was always approximated to nerve tissue, and all foreign material as far as possible was kept out of the path of the regenerating fibers.

In many experiments absolute alcohol was injected into the end of the nerve to determine its effect on the various types of repair and neuroma formation.

*2 Methods of Repair*—A number of different methods were tried, such as tubes of foreign bodies and of fascia, but all were discarded except the three following.

(a) *Anastomosis of the central and peripheral ends of an injured nerve into longitudinal incisions in a normal nerve*. These longitudinal

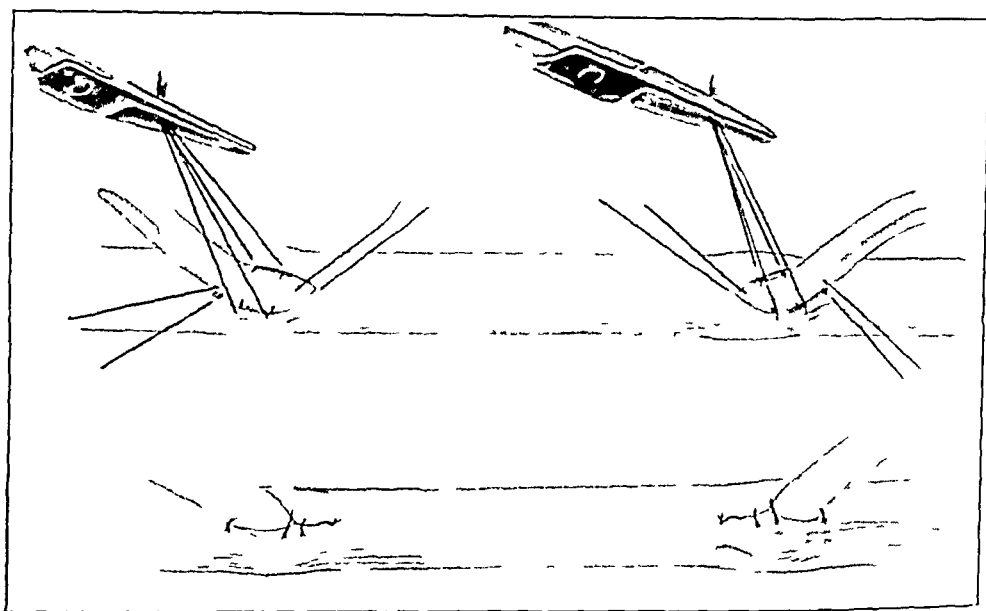


Fig 1—Anastomosis of the central and peripheral ends of an injured nerve into longitudinal incisions in a normal nerve

incisions were each about 6 mm long and as nearly as possible in the same quadrant of the nerve. When the nerve to be implanted had a neuroma on its end from a previous operation, it was cut back until normal looking axis cylinders were exposed. The ends of the nerve were then sutured into the longitudinal slits and held in place by sutures passed through the perineural sheaths. This type of suture is illustrated in Figure 1. The peroneal nerve was cut and sutured into the tibial nerve in each case (eighteen experiments).

(b) *Anastomosis of the central and peripheral ends of an injured nerve to flaps cut in the same quadrant of a normal nerve* (Fig 2). The peroneal nerve was cut and sutured to flaps in the tibial nerve. Three sutures were used at each line of suture (fifteen experiments).

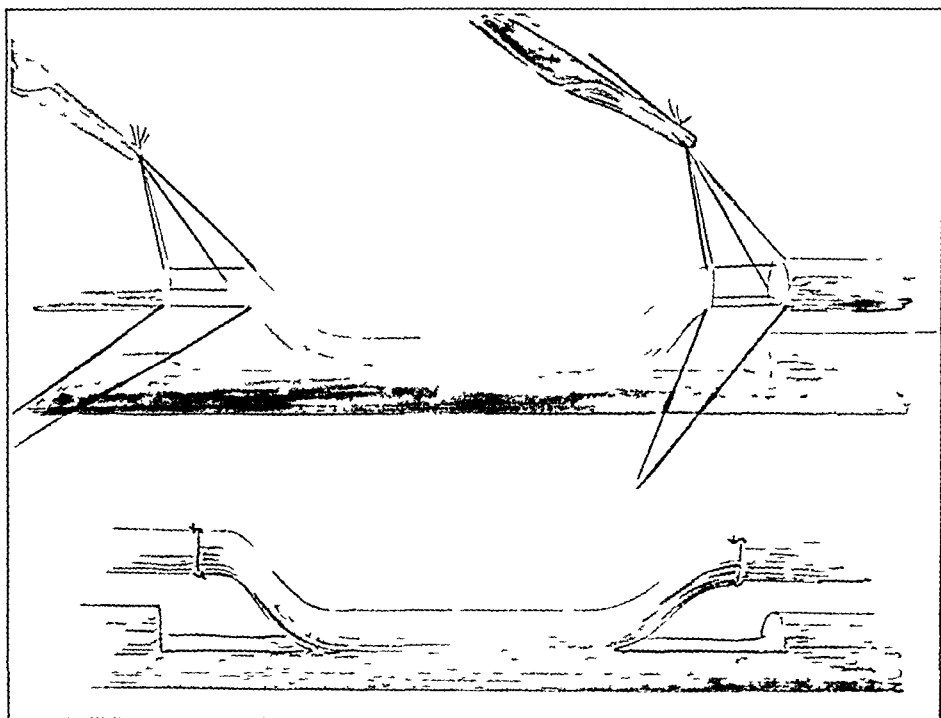


Fig 2—Anastomosis of the central and peripheral ends of an injured nerve to flaps cut in the same quadrant of a normal nerve

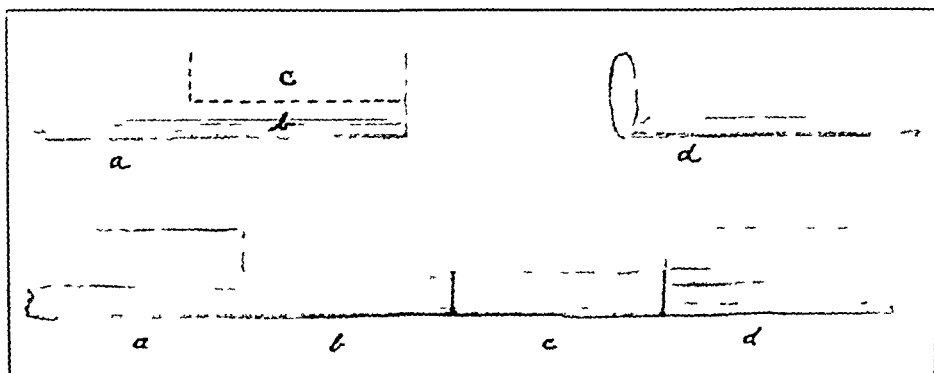


Fig 3—Autotransplant of half of the central end of the injured nerve the removed segment being just long enough to bridge the defect Portion C is completely excised

(c) *Autotransplant of half of the central end of the injured nerve, the segment removed being just long enough to bridge the defect (auto-autotransplant)* (Fig 3) From three to four sutures were used at each suture line (sixteen experiments) A few end-to-end sutures and a few cable autotransplants were performed as controls

In three experiments the nerve was cut and allowed to fall back into its former bed without any attempt to bring the ends together In two of these experiments absolute alcohol was injected into the central end to test its influence upon neuroma formation

3 *Physiologic Tests*—Following the operations the nerves were exposed at varying intervals, ranging from three days to five months, and tested physiologically to determine any signs of regeneration The animals were always anesthetized for these tests The tests consisted of stimulating the nerve centrally and peripherally to the point of repair with small platinum electrodes attached to a faradic coil A current just strong enough (threshold current) to cause a response in a normal nerve was used The nerve during the stimulation was raised from its bed so that it was separated from all surrounding tissues to avoid spread of the current Two responses were looked for a peripheral one which consisted of contractions of the muscles, and a central one which consisted in the reflex stimulation of respiration recently described by one of us (Malone)<sup>12</sup> In the accompanying tables these two types of response are referred to as peripheral and central response

In some cases each muscular branch of a nerve was isolated and muscular contractions were noted when each of these nerve branches was stimulated In a few experiments, chronomyometer<sup>13</sup> tests were applied to the muscles before the nerve was exposed

4 *Anatomic Methods*—Following the physiologic tests the animals were killed and the gross appearance of the nerve noted The nerve was then removed, a diagram was made of it, it was stained in silver pyridin<sup>9</sup> and examined microscopically Some of the specimens were cut from 5 to 10 microns thick in cross-section, others longitudinally Every fifth section was mounted so that nerve fibers could be traced systematically and these series of slides enabled us to visualize the reconstructed nerve A few series were stained with Marchi, cut longitudinally and studied serially

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## III RESULTS WITH DIFFERENT TYPES OF REPAIR

In Table 1 are summarized the results of the eighteen experiments in which the two ends of the nerve were implanted into an adjacent nerve. The results in this type of experiment may be considered under two headings, physiologic and histologic.

(1) *Physiologic* —(a) The distance from the point of anastomosis to the muscles innervated by the injured nerve was from 10 to 14 cm. Regeneration was complete as indicated by the muscular response in every case by the ninetieth day. This would make the average rate of regeneration approximately 1 cm per week. Though the nerve has a normal physiologic response at the end of ninety days, histologically it does not have the appearance of a normal nerve. The clear spaces about the axis cylinders that are seen in a normal nerve are not present; instead, this space appears filled by a pale greenish staining homogeneous mass in the silver pyridin specimens. We presume this substance is preformed myelin.

(b) Complete regeneration occurred irrespective of the distance between the two ends of the implanted nerve. This distance varied from 1 to 6 cm. When the distance between the two ends was from 1 to 2 cm, regeneration seemed to occur a week or two sooner than when the interval was from 5 to 6 cm. The explanation for this observation is not perfectly clear. It may be that the number of fibers growing from the normal nerve into the implanted nerve are not sufficient to give an early reaction or it may be that the fibers growing from the central end of the injured nerve do not reach the peripheral end so soon. The latter is just what one would expect, for they have from 3 to 4 cm farther to grow.

(c) Regeneration occurs almost as rapidly in cases of secondary sutures performed two months after an injury as in those performed immediately after an injury.

(d) In experiments in which the distance between the central and peripheral ends of the implanted peroneal nerve was but from 1 to 2 cm and in which complete regeneration had occurred, stimulation of the *central* end of the peroneal nerve produced good contractions of the muscles innervated normally by the peroneal nerve and often a weak contraction of a muscle innervated by the tibial nerve. The longer the gap, however, the more frequently did muscles contract which were supplied by the tibial nerve in addition to those supplied by the peroneal nerve. This indicated clearly that some peroneal fibers had grown down the tibial nerve as well as down the peroneal. In order to prove this positively the following experiment was tried. After complete physiologic recovery had occurred in one of the implants of the peroneal nerve into the tibial nerve the tibial nerve proximal to the implantation

TABLE 1—ANASTOMOSIS OF CENTRAL AND PERIPHERAL ENDS INTO SLITS IN INTACT NERVE, LEFT PERONEAL NERVE CUT AND ANASTOMOSED TO INTACT LEFT TIBIAL IN EACH CASE

Experiment Number	Days Between Repair and Examination	Distance Between Central and Peripheral Suture Lines, Cm	Physiologic Response		Histologic		Remarks
			Peripheral	Central	Macroscopic	Microscopic	
113	3	2	Negative in peroneal positive in tibial	Negative in peripheral peroneal	Little scarring	Degeneration not complete no regeneration seen	No remark in protocol about tibial reaction
123	8	1.5	Negative in peroneal positive in tibial	Negative in peripheral peroneal, positive in peripheral tibial	Little scarring or bulbs	Some regeneration 1 cm distal to central suture	
109	14	1	Negative in peroneal positive in tibial	Negative in peroneal	Little scarring small bulb at central suture	Partial regeneration through both suture lines	No remark in protocol about tibial reaction
5	27	3	Negative in peroneal positive in tibial	Not tested	Small bulbs at suture lines	Some regeneration in peroneal, 1 cm distal to distal suture	
13	38	1	Not tested	Not tested	Little scarring or bulbs	Some regeneration in distal peroneal	Secondary suture 53 days after cutting peroneal
27	52	1	Not tested	Not tested	Little scarring or bulbs	Complete regeneration 2 cm in distal peroneal not studied further	
37	52	1	Not tested	Not tested	Little scarring or bulbs	Complete regeneration 2 cm in distal peroneal not studied further	Central end not anastomosed, secondary suture 12 days after cutting peroneal
23	52	1.5	Not tested	Not tested	Little scarring or bulbs	Complete regeneration 2 cm in distal peroneal not studied further	
129	60	5	Negative in peroneal	Positive in peroneal	Some scarring and small bulbs	Good partial regeneration 5 cm distal to distal suture	Secondary suture 49 days after cutting peroneal
77	79	1	Negative in peroneal	Positive in peroneal	Little scarring or bulb formation	Partial regeneration 10 cm distal to distal suture	
101	90	1.5	Positive in peroneal positive in tibial	Positive in peroneal	Little scarring and bulbs	Regeneration complete in tibial and peroneal	Animal lost
127	90	5	Positive in peroneal positive in tibial	Positive in peroneal	Little scarring and bulbs	Regeneration to muscles still occurring	
81	106	5	Weak peroneal, strong tibial	Positive in peroneal	Little scarring and bulbs	Regeneration complete	Central end not anastomosed, secondary suture 12 days after cutting peroneal
53	124	1	Not tested	Not tested	Little scarring and bulbs	Regeneration complete	
83	150		Positive in both but weaker in peroneal	Positive in peroneal	Little scarring and bulb	Regeneration almost complete	Secondary suture 49 days after cutting peroneal
85	150	6	Positive in peroneal positive in tibial	Positive in peroneal	Little scarring and bulbs	Regeneration complete	
51	221	1	Positive in peroneal positive in tibial	Positive in peroneal	Little scarring and bulbs	Regeneration complete	Animal lost
15		1.5			Little scarring and bulbs	Regeneration complete	

of the peroneal nerve was cut. After eighteen days, tests were made and it was found that the peroneal muscles responded actively while the muscles supplied by the tibial nerve also responded, but weakly. This physiologic evidence indicated that some peroneal fibers had grown down the tibial nerve. This was confirmed histologically for sections

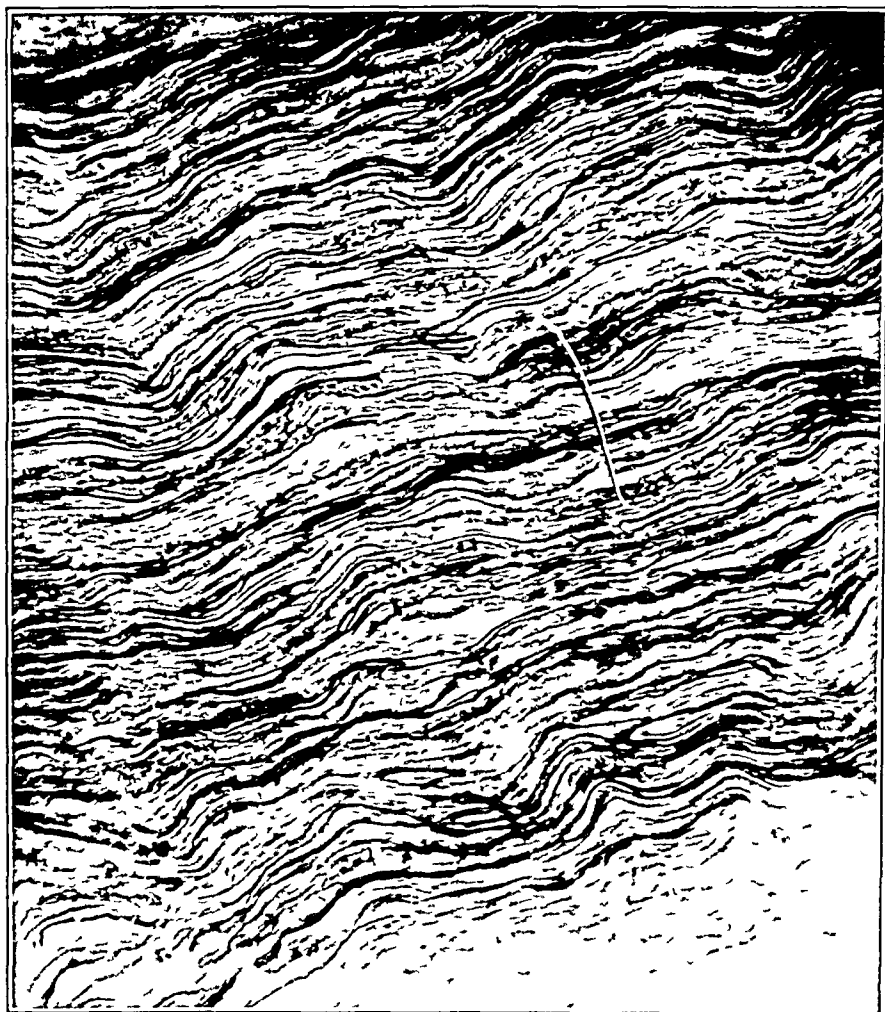


Fig 4—Longitudinal section of peroneal nerve peripheral to implantation, showing large number of axis cylinders

of the peroneal nerve showed a nearly normal number of axis cylinders (Fig 4), while the tibial nerve showed but a few axis cylinders (Fig 5).

(c) Stimulation of the tibial nerve central to the peroneal anastomosis produced strong contractions of the tibial group of muscles and weak contractions of the peroneal group. From this and the foregoing observation, it is apparent that fibers grew from the tibial into the peroneal and vice versa.

In order to demonstrate that complete regeneration had occurred to every muscle, the various branches of the tibial and peroneal nerves were isolated and stimulated. The muscles responded just as vigorously, irrespective of the origin of their nerve supply.

(f) In all cases in which a muscle contraction occurred, the respiratory response described by one of us recently (J Y M) was also present. This respiratory response was also present in all cases in which the axis cylinders had grown through the nerve block, even though the fibers had not yet grown down to the muscles.



Fig 5—Longitudinal section of tibial nerve peripheral to anastomosis showing very few axis cylinders. Figures 4 and 5 are from a case of double implantation of peroneal nerve into tibial nerve, complete regeneration at end of five months, tibial nerve cut central to anastomosis eighteen days before specimen removed, all fibers in Figures 4 and 5 that did not degenerate must have had their origin from the central end of the peroneal nerve.

2 *Histologic*—It is difficult to trace funiculi down a nerve, but this can be done quite satisfactorily in serial sections. The difficulty arises from the fact that at every suture line the fibers form whorls, especially at the central point of anastomosis. We have found, however, that peroneal fibers grew down the tibial nerve (Fig 6), and when they reach the point where the distal end of the peroneal nerve had been

implanted, some fibers grew into the tibial and some into the peroneal nerves. By the study of osmic acid preparations, it was possible to trace fibers from the central end of the peroneal nerve through the tibial nerve out into the peroneal nerve. The longer the gap between the two ends of the peroneal nerve, the more do tibial fibers grow into the peripheral peroneal. This we believe is explained by the fact that they are "the first on the ground," that is, they originate from the injury of the tibial nerve at the distal implantation of the peroneal and



Fig 6—Point of anastomosis where the central end of the peroneal nerve (A) was implanted into the tibial nerve (B)

have filled up many of the axis cylinder spaces before the fibers from the central peroneal nerve get there.

At the point of suture axons are seen passing into funiculi and also between them. There are far more axons at the point of anastomosis than in the normal nerve above the site of anastomosis and grossly the nerve was larger at these points. There is also an excess of fibers distal to the anastomosis for about three months (Fig 7) but at the end of five months (Fig 8) the number of fibers had been reduced to



about normal. This overproduction of axons merely corroborates Osborne and Kilvington's<sup>6</sup> and Ranson's<sup>9</sup> observations that the growing point of an axon may split into several fibrillae, but evidently the unused fibrillae degenerate later.

*Results After Double Anastomosis to Flaps Cut into a Normal Nerve*—In this series, fifteen experiments were performed (Table 2). The results were essentially the same as those in the first series and were



Fig 7—Part of peroneal nerve distal to suture showing regeneration of nerve after a double implantation at end of three months, and the excess of axis cylinders and the absence of medullary sheaths. At this stage the physiologic response of this nerve was normal, magnification same as in Figures 8 and 9.

about as good. There were two notable differences. First there was more bulb formation at the site of anastomosis and more whirling of axons, but not enough evidently to interfere with regeneration, and, secondly, there was less crossing of peroneal fibers into tibial and tibial into peroneal.

*Results of Autotransplant of a Segment of Half of the Central Portion of the Injured Nerve into the Gap*—There were sixteen experiments in this series which are recorded in Table 3.

TABLE 2—ANASTOMOSIS OF CENTRAL AND PERIPHERAL ENDS TO FLAPS CUT IN INTACT NERVE, LEFT PERONEAL CUT AND ANASTOMOSED TO FLAPS CUT IN LEFT TIBIAL

Experiment Number	Days Between Repair and Examination	Distance Between Central and Peripheral Suture Lines, Cm	Physiologic Response		Histologic		Remarks
			Peripheral	Central	Macroscopic	Microscopic	
119	3	1	Negative in peroneal, positive in tibial	Negative in peroneal	Little scarring or bulbs	No degeneration or regeneration noticeable	Animal discarded
125	3	1	Not tested	Not tested	Little scarring or bulbs	Tibial looks normal, peroneal regeneration 1 cm distal to distal suture	
103	13	1.5				Some regeneration 1 cm distal to distal suture line	
135	20	5.5	Negative in peroneal	Negative in peroneal	Little scarring on bulbs	Tibial looks normal, peroneal some regeneration 2 cm distal to distal suture line	No remark in protocol about tibial reaction
115	21	1	Negative in peroneal, normal in all branches of tibial	Not tested	Little scarring but definite bulbs at suture lines	Tibial, all funiculi look normal, peroneal good regeneration 2 cm distal to distal suture	
7	32	2.5	Negative in peroneal normal in tibial	Positive in peroneal as far as 2 cm distal to distal suture line	Some scarring and bulbs at both suture lines	Regeneration good in peroneal to 2 cm distal to distal suture	
41	43	1.5	Not tested	Not tested	Little scarring or bulb formation	Good regeneration 1 cm distal to suture, fair at 6 cm very doubtful in muscles	
107	60	1	Negative in peroneal positive in all branches of tibial	Positive in peroneal and tibial	Little scarring, small bulbs at both suture lines	Regeneration 10 cm distal to distal suture in peroneal	
25	81	1.5	Not tested	Not tested	Little scarring, small bulb at central suture line	Regeneration complete	Second try suture 53 days after cutting peroneal
97	120	0	Positive in tibial and peroneal	Not tested	Some scarring about nerves and some bulb formation at central suture line	Regeneration complete	
95	120	1	Positive in both	Positive in tibial and peroneal	Some scarring, small bulbs	Regeneration complete	
55	136	1	Not tested	Not tested	Some scarring small bulbs	Regeneration complete	
71	152	1	Positive in tibial, positive in peroneal	Positive in peroneal	Some scarring, small bulbs	Regeneration complete	
99	200	2	Not tested	Not tested	Some scarring, small bulbs	Regeneration to muscles but some regeneration figures present in distal half of nerve	
19		12 mm					Animal lost

TABLE 3—AUTOTRANSPLANT OF HALF OF DIVIDED CENTRAL NERVE

TABLE 3—ACTIONS				Histologic		Remarks	
Experiment No	Nerve Used	Days Between Repair and Exam	Length of Transplant, cm	Physiologic Response			Microscopic
				Peripheral	Central		
121	Left tibial	3	2	Negative	Negative	Axons and twisting of axons to central suture	Tube of fascicula around repaired area
117	Left tibial	10	1	Negative	Negative	Regeneration just through distal suture	
11	Left tibial	20	2	Negative	Not tested	Scar tissue about central end invaded by axons	
45	Left tibial	21	1	Not tested	Not tested	Few axons 1 cm distal to distal suture	
47	Left peroneus	23	1	Not tested	Not tested	Axons 1 cm distal to distal suture	
21	Left tibial	24	1	Not tested	Not tested	Axons 1 cm distal to distal suture	
57	Left tibial	25	1	Not tested	Not tested	Regeneration just through distal suture line	
49	Left tibial	26	1	Not tested	Not tested	Regeneration partly 1 cm distal to distal suture line	
71	Left tibial	46	1	Not tested	Not tested	Regeneration at least 1 cm distal to repair (not studied further)	
105	Left tibial	60	3	Negative	Good	(Complete regeneration 1 cm distal to repair occasional axon at nearest muscle (9 cm))	
99	Left tibial	90	2	Normal	Good	Regeneration complete	Animal lost
97	Left tibial	120	1	Normal	Good	Regeneration complete	
65	Left tibial	153	1	Not tested	Not tested	Regeneration complete	
67	Left tibial	169	1	Normal	Good	Regeneration complete	
29	Left tibial	234	1	Normal	Good	Regeneration complete	
59	Left tibial	4	4				

1 *Physiologic* —(a) As judged by the return of function, complete regeneration was observed about as rapidly as after the other methods of repair (ninety days)

(b) The central physiologic response was always present by the sixtieth day after the suture. How much earlier than this it was present we were unable to determine in this series as none of the nerves were tested physiologically before that time, except three and ten days after repair, when it had not yet appeared

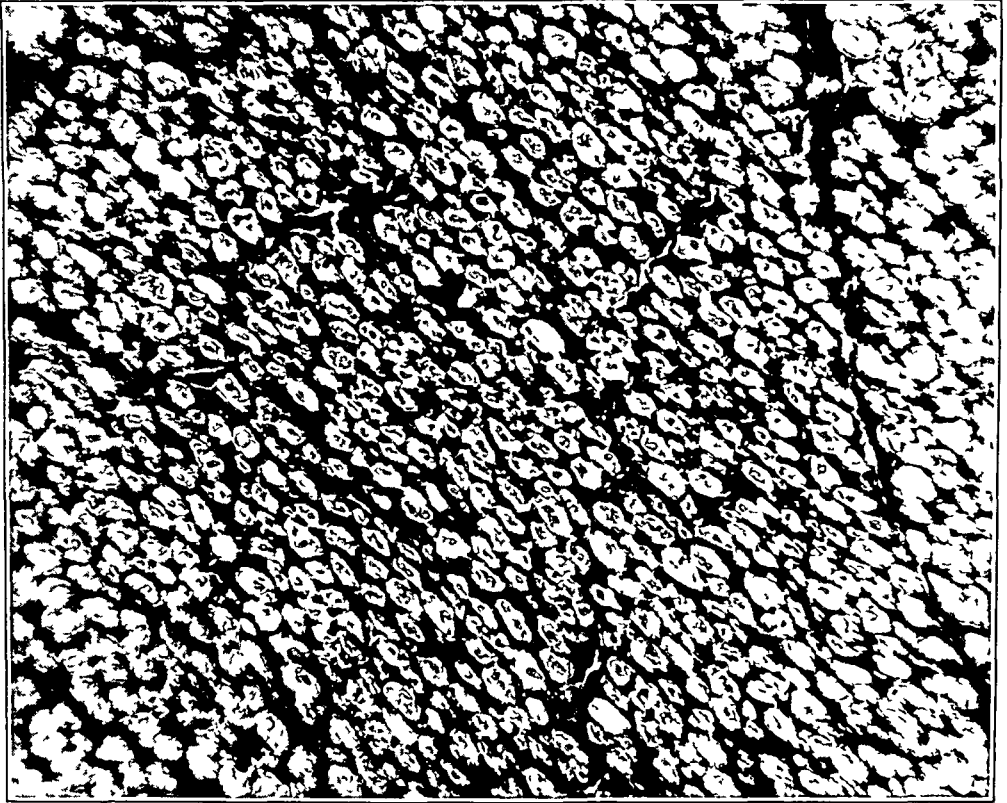


Fig 8—Cross-section of tibial nerve distal to auto-autotransplant five months after repair, all the medullary spaces are filled with axis cylinders but there is no excess of axis cylinders as in Figure 7

(c) Peripheral response when it did appear was as active in one branch as in another, showing that regeneration was occurring throughout the nerve

2 *Histologically* —Axis cylinders grow from every point where they have been cut, but most of the fibers that get to the peripheral portion of the nerve grow through the autotransplant from those axis cylinders which lie in direct contact with the transplant. Some of the fibers grow down between the funiculi of the autotransplant and reach the peripheral end of the nerve. Some fibers were observed growing from the central

end of the nerve from which the autotransplant had been removed. These fibers grow along the nerve as well as the transplant and reach the peripheral end of the nerve, but as there is some neuroma formation at that point, many of the axons never get through. Cross-sections were taken from the nerve where the transplant had been removed (Fig 3*b*), from the transplant *c* and both were compared with cross-sections through *a* and *d*. These showed that the number of axis cylinders in the transplant was far greater than in half the original

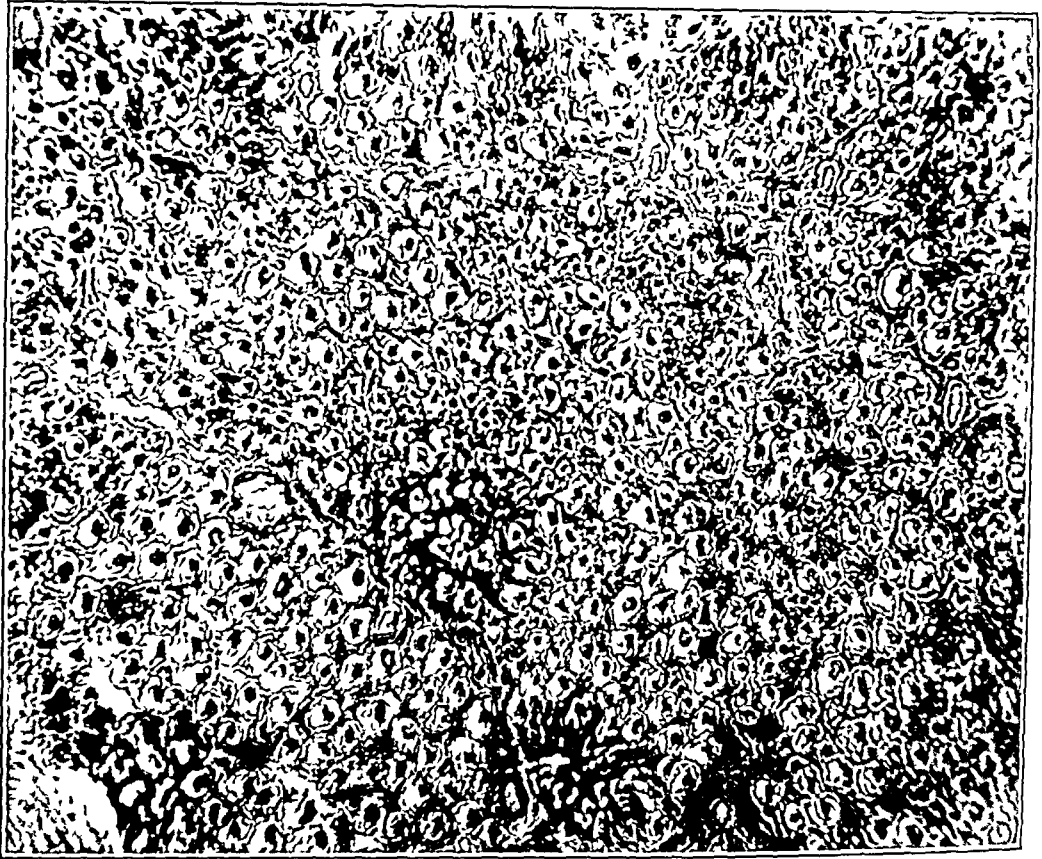


Fig 9—Cross-section of peroneal nerve central to double implantation showing the appearance of a normal nerve with well formed medullary spaces and large number of nonmedullated fibers

nerve, and, though not actually counted, approximated the number of axis cylinders in the normal nerve. All the medullary tubes in the peripheral portion of the nerve after complete regeneration has taken place are completely filled with axis cylinders (Fig 8). There is a marked overproduction of axis cylinders, for some of the medullary tubes contain several axis cylinders, and in some cases as many as five. This overproduction is striking at the end of three months, but when such nerves are studied after a five months' period, the nerve looks normal, and evidently the surplus number of axons have disappeared. As

was to be expected, a moderate amount of neuroma formation was observed both at the point where the transplant was removed and also at the distal suture line. A most interesting finding has been that nerves, when they first give a normal physiologic response after regeneration, histologically do not look normal (Figs 7 and 9). The clear medullated sheaths are not present, but from six to eight weeks after that, such a nerve looks normal. This would indicate clearly that a motor nerve may functionate before it has regained its normal histologic appearance.

#### IV DISCUSSION OF THE MERITS OF VARIOUS TYPES OF OPERATION FOR BRIDGING NERVE DEFECTS

Our work has convinced us that any type of tissue other than nerve tissue used to bridge a nerve defect is, as a rule, unsatisfactory. This is merely confirmatory of what other observers have noted.

TABLE 4—PRIMARY END-TO-END SUTURE

Experiment No	Days Between Repair and Examination	Physiologic Response		Histologic	
		Peripheral	Central	Macroscopic	Microscopic
33	20	Not tested	Not tested	Little scarring or bulb	Regeneration complete through suture line and fair 2 cm distal
93	32	Negative	Pos 2 cm distal to suture line	Little scarring and small bulb	Regeneration partial 4 cm distal to suture line
89	150	Positive	Not tested	Little scarring and small bulb	Regeneration complete
69	157	Positive	Negative (anesthetic deep)	Little scarring and small bulb	Regeneration complete 6 cm distal (not studied farther) some tendency to neuroma formation at suture line
73	161	Positive	Positive	Little scarring and small bulb	Regeneration complete
91	240	Positive	Not tested	Little scarring and small bulb	Regeneration complete some neuroma formation at suture line

The type of repair that is most satisfactory for bridging defects so large that end-to-end anastomosis is not possible is the implantation of the central and peripheral ends of the nerve into an adjacent healthy nerve. Such a procedure in dogs gave a very satisfactory result and did not interfere with the function of the healthy nerve. When the gap was 2 cm or less many fibers from the central end grew into the peripheral end of the nerve. The larger the gap, the fewer fibers from the central end grew into the peripheral end, but some could always be traced into the peripheral stump and also into the normal nerve. As the maximum source of new axis cylinders is always desirable, this procedure should always be followed regardless of the size of the gap. There are two conditions in which the double implantation method is impracticable. One of these is encountered when the severed nerve is

larger than the nerve into which an implantation could be made. The other condition occurs when there is no adjacent nerve available. In both these cases the method of auto-autotransplant is preferable.

The second type of anastomosis we have described has no advantages over the foregoing, either as to rate of regeneration, completeness of recovery or central fibers connecting with the distal end. It has the great disadvantage that much more injury is done to the normal nerve and there is more tendency to neuroma formation.

The method of auto-autotransplant described in this communication has the advantage that no normal nerve has to be destroyed and that it can all be carried out in one operative field. The results, in dogs, seem at least as good as those obtained by Huber's<sup>2</sup> autotransplant.

#### V. GENERAL CONSIDERATIONS

In every type of nerve suture, no matter how perfect the approximation is, there are whorls as the fibers grow out, so that corresponding fibers do not join, consequently some reeducation is always necessary. The objection that one might expect would be raised to the removal of part of a nerve is that certain funiculi going to certain muscle groups would thereby be injured or destroyed. The existence of internal plexuses in nerves, which has been the thesis of the work of Dustin,<sup>14</sup> Heinemann,<sup>15</sup> Langley and Hashimoto,<sup>5</sup> and most recently McKinley,<sup>16</sup> disposes of this objection.

Our experiments lend support to this contention. Cross-sections of the sciatic nerve trunk, taken at 3 mm intervals, showed a variation in the number and size of the funiculi. This variation in number was as follows: three, seven, seven, four, three. Cross-sections of the posterior tibial nerve of a man were shrunk to such an extent by the fixative that accurate counts were not possible, but here also a marked variation in the number of funiculi at different levels was noted.

As further evidence bearing on this question we wish to point out that after cutting about one third of the diameter of the tibial nerve all the muscles supplied by the nerve reacted when each nerve branch to each group of muscles was stimulated. Whether there was any sensory impairment, of course, could not be determined on animals. Furthermore, a cross-section of the nerve below the point of section studied after degeneration was complete showed that the degenerated

14 Dustin, A. P. Les lésions post-traumatiques des nerfs: contribution à l'histopathologie du système nerveux périphérique chez l'homme, *Ambulance de "L'Océan," La Panne*. Extrait du fascicule II, December, 1917.

15 Heinemann, O. Weitere Untersuchungen über den inneren Bau der grossen Nervenstämme, *Arch f. klin. Chir.* **109**: 121, 1917.

16 McKinley, J. C. The Intraneural Plexus of Funiculi and Fibers in the Sciatic Nerve, *Arch. Neurol. & Psychiat.* **6**: 377 (Oct.) 1921.

fibers were scattered throughout the nerve and did not occupy one portion of the nerve as they should have if the fibers travel down a nerve in the same sector

Secondary sutures made several months after injury are as successful as primary sutures if the funiculi are brought into perfect approximation without a connective tissue barrier. The physiologic recovery was somewhat slower than in a primary suture. We have been unable to determine any reason for this.

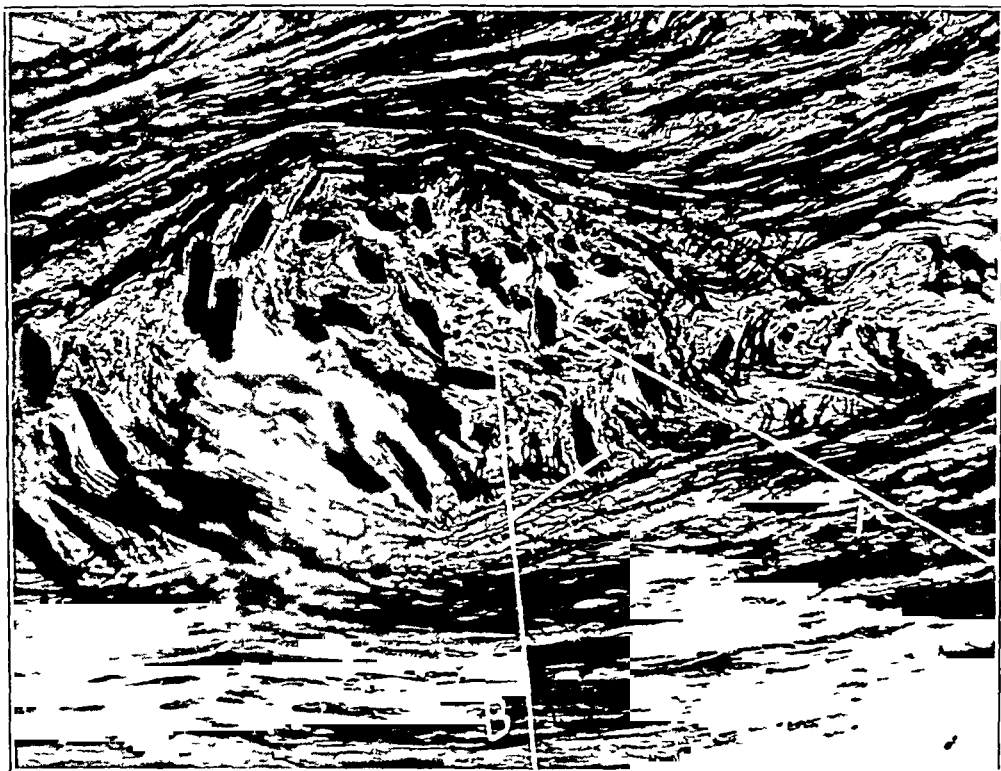


Fig 10—Silk suture with regenerated axis cylinders passing between the strands of silk. *A*, silk, *B*, axis cylinders

Injection of absolute alcohol into the cut end of a nerve reduced the tendency to neuroma formation in two experiments and to some extent in a third, but we were unable to obtain a picture similar to that obtained by Lewis and Huber<sup>17</sup> in rabbits. Our observations tend to show that the injection of absolute alcohol does not completely prevent neuroma formation, though it does inhibit it. Injection of alcohol into the nerve trunk at the site of suture with the idea of preventing neuroma formation seemed of no value, though it did not interfere

<sup>17</sup> Lewis, Dean, and Huber, G. C., Amputation Neuromas. Their Development and Prevention. *Arch Surg* 185 (July) 1920



with the process of regeneration or prolong this process. The distortion of axons and interference with their growth at the site of suture is due to those factors that have been emphasized in the publications that have appeared in the last few years. Connective tissue is the great obstacle, and anything that may increase the formation of scar tissue is to be avoided. Occasionally, in the larger human nerves, bleeding from a small vessel is very troublesome and cannot be stopped by the application of heat. In such cases, rather than leave a fine ligature in the center of the regenerating nerve, we have for some years distended the end of the nerve with salt solution. Another and most important factor in getting good regeneration is the accurate approximation of the nerve ends so that the exposed nerve ends come in contact. To accomplish this most perfectly, sutures, as far as possible, should be placed in the perineural tissue and not through the fasciculi. We are convinced that sewing individual fasciculi together is a physical impossibility as well as not being absolutely necessary. In this connection, it may be well to emphasize again that extremely fine silk heals in with far less reaction than does catgut. It is quite astonishing to note that the reaction about silk is so slight that frequently axons can be seen growing between the strands of a silk ligature (Fig 10).

#### SUMMARY AND CONCLUSIONS

1 Three methods of bridging defects in nerves have been studied by a combination of physiologic and histologic methods.

2 It has been shown that nerve fibers will grow down the trunk of a healthy nerve through a longitudinal incision without impairing its function and part of the fibers connect up with the peripheral end. It is, therefore, of distinct advantage to implant the central end of a cut nerve as well as the peripheral end.

3 On account of the branching of regenerating fibers, enough axons are produced when a nerve is cut longitudinally to fill the sheaths in the implanted nerve, indicating that in a nerve anastomosis, an end-to-side implantation is perfectly satisfactory. This confirms our clinical experience. We have for years practiced this method of anastomosis in faciohypoglossal anastomosis.

4 The test described by one of us (Malone) for determining that nerve fibers have grown across a point of suture has proved a valuable aid in determining at an early date whether or not a nerve is regenerating.

5 The study of cross-sections of nerves as well as the results following the method of auto-autotransplant described in this paper throw doubt on, and we believe disprove, the contention that peripheral nerves have an internal topography as maintained by Stoffel.

6 Though absolute alcohol may inhibit to some extent the formation of neuromas, it does not absolutely prevent them

7 The most important factor in a successful nerve anastomosis is the accurate approximation of the nerve ends so that there is no tissue between them which may interfere with the regeneration of the fibers. Every effort, of course, should always be made to bring them together in their original anatomic relation, but, owing to the presence of internal plexuses in nerves, it is not so essential as has been supposed heretofore. Whenever a nerve regenerates, whorls are formed at the regenerating end, consequently the central end of a fiber does not necessarily connect with its corresponding peripheral end.

8 The method of auto-autotransplant described in the foregoing pages for bridging defects too long to permit of an end-to-end anastomosis is to be preferred to cable autotransplants because no normal nerve has to be injured and the operation can be carried on in one field.

9 The method of choice for bridging large defects whenever possible is the double implantation method of anastomosis. Its advantage over the auto-autotransplant lies in the fact that *some* axis cylinders have only one suture line to grow through, while in the auto-autotransplant they all have to go through two suture lines.

# PREOPERATIVE TREATMENT OF MALIGNANT TUMORS OF THE BLADDER BY RADIUM

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In many instances, the most desirable results in treating malignant tumors of the bladder are obtained by a combination of surgery and the use of the minimal quantity of radium that will effectually limit further activity of the malignant cell. Russ and Chambers,<sup>1</sup> in 1913, showed that long periods of radiation killed the cells of transplanted rat tumors which then were absorbed rapidly. After a shorter radiation, even though the grafted tumor failed to develop, the cells remained at the site of inoculation for a long time, but their capacity for proliferation was diminished. Wassermann<sup>2</sup> exposed extirpated rat cancer to radium rays from mesothorium and inoculated the cancer into susceptible animals, but growths did not result. He asserted that the death was nuclear, not cellular, the proliferating power of the cell was destroyed but the cell was not killed. Price<sup>3</sup> found that after mouse tumors had been exposed to radium, the power of cell division was incomplete, as was shown by the decrease in the number of mitotic figures. Prime<sup>4</sup> believes that the inability of inoculated fragments to grow depends to a certain extent on the failure of the nucleus to perform the usual steps preliminary to division. In irradiated tissue, multinucleated cells (those with division of nuclei but not of cytoplasm) were not found, but rather cells with nuclei many times larger than that of the normal cell. Prime concludes that radium in sufficiently large doses will injure the nucleus of the cell and so inhibit further division, which must eventually result in the death of the cell.

It is probable that mitotic figures have a direct bearing on the recurrence of malignant growths and the successful transplantation of

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1 Russ, S, and Chambers, Helen. On the Action of Radium Rays upon the Cells of Jensen's Rat Sarcoma, *Proc Roy Soc London*, B **86** 482-489, 1913

2 Wassermann, A. Analyse der Wirkung radioaktiver Substanzen auf Mausekrebs, *Deutsch med Wchnschr* **40** 524-528, 1914

3 Price, J C, and Mottram, J C, quoted by Prime, F. Observations upon the Effects of Radium on Tissue Growth in Vitro, *J Cancer Res* **2** 107-130 (April) 1917

4 Prime, F. Footnote 3

the cells Evans<sup>5</sup> studied the relationship between mitotic figures and malignancy in uterine myomas and found that only from tumors containing large numbers of mitotic figures were the cells able successfully to invade the tissue and recur after the removal of the original growth

Radium is usually employed in the form of radium salt, in which the beta rays are filtered out and the gamma rays alone used The limited range of the beta rays, from 6 to 8 mm, permits them to be effective only in exceptional cases, in which they usually are screened off in order to prevent destruction of the tissues intervening between the capsule and the point of irradiation The beta rays, being many times more numerous than the gamma rays, are extremely effective at short range They have a correspondingly greater ionizing force over a very limited area In unscreened radium, the beta rays are filtered out by the adjacent tissue, over which they exert an extremely destructive influence Wood and Prime<sup>6</sup> have shown that if pure gamma rays only are used, the exposure necessary for cellular destruction is eight times as long as that required when gamma and beta rays combined are employed Wedd and Russ<sup>7</sup> found that excised tumors irradiated one hour with 5 mg of unscreened radium rays do not proliferate on transplantation, but that an exposure of eighteen hours to gamma rays alone from 5 mg of radium is insufficient to inhibit such growth

By burying tubes containing unscreened radium emanation directly in the growth, these highly effective beta rays may be utilized Janeway<sup>8</sup> asserts that 100 per cent of radium efficiency may thus be directed against the tumor By employing the numerous beta rays, small amounts of radium become very effective The tubes permit accurate, measured distribution of the radium rays, and thus, with the short range of the extremely active beta rays, an exceptionally high dosage may be employed without damage to normal tissues Bagg<sup>9</sup> planted emanation points in rat tumors and found that they produced areas of necrosis about 1 cm in diameter which were practically uniform for varying amounts of the emanation

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5 Evans, N Malignant Myomata and Related Tumors of the Uterus, *Surg, Gynec & Obst* **30** 225-239 (March) 1920

6 Wood, F C, and Prime, F The Action of Radium on Transplanted Tumors of Animals, *Ann Surg* **62** 751-765, 1915

7 Wedd, B H, and Russ, S The Effect of Roentgen and Radium Radiations upon the Viability of the Cells of Mouse Carcinoma, *J Path & Bacteriol* **17** 1-11, 1912

8 Janeway, H H Treatment of Cancer, Particularly of the Tongue Tonsil and Rectum, by Buried Emanation, *Am J Roentgenol* **6** 92-101 (Feb) 1920

9 Bagg, H I The Action of Buried Tubes of Radium Emanation upon Normal and Neoplastic Tissue, *Am J Roentgenol* **7** 536-544 (Nov) 1920

Radium is most commonly employed in the treatment of surface growths, especially of the skin, breast, and cervix. Tumors of the deeper structures, especially malignant growths of the stomach and urinary bladder, have not been considered suitable for radium treatment.

Certain types of tumors of the bladder respond to excision, others offer an extremely poor prognosis. Owing to the difficulty of completely eradicating the tumor and its frequent cellular transplants, recurrence is early and extensive. This is particularly true of the solid meaty epitheliomas commonly occurring in the base of the bladder. Small infiltrating wedges of actively malignant cells, which project down through the muscle bundles, are often cut across when a portion of the bladder wall is excised. The undisturbed clumps of cells remain in the normal tissue, act as foci, spread rapidly and extensively, and often attain an inoperable size shortly after operation. Since epithelial tumors of the bladder rarely metastasize, patients who die from malignancy of the bladder usually succumb because of the local condition. Any procedure that would aid in effectually eliminating the local condition would in many cases cure the patient. Tumors recurring in patients who return at three-month intervals after operation, in response to follow-up letters, are generally small and respond readily to intravesical manipulation.

There are several types of instruments for the endovesical application of radium to tumors of the urinary bladder. In some cases in which the tumor is situated in the base of the bladder, it is possible to plant radium needles directly in the tumor through the perineal tissues, as in the treatment of malignant disease of the prostate. Young<sup>10</sup> has described a method for applying radium in the capsule to the tumor under actual vision. Woolston<sup>11</sup> has devised an apparatus whereby the radium may temporarily be fastened to the malignant area. Both Lewis<sup>12</sup> and Janeway have described instruments by means of which tubes of emanation may be planted directly in tumors.

By direct cystoscopy, any type of needle may be used if it is sufficiently long to pass through the lumen of the instrument and contains a movable stylet or plunger. The majority of vesical tumors are directly in line with the urethra, being situated on the base, dome, or

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10 Young, H. H. Cancer of the Prostate, in Cabot, Hugh. *Modern Urology in Original Contributions by American Authors*, Philadelphia, Lea & Febiger, 1918, vol. 1.

11 Woolston, W. H. An Instrument for the Application of Radium to Tumors of the Bladder, *Surg., Gynec. & Obst.* **31** 627-629 (Dec.) 1920.

12 Lewis, R. M. Apparatus for Implantation of Radium Emanation Points, *Surg., Gynec. & Obst.* **30** 528 (May) 1920.

posterior or lateral walls, where they may be reached with a straight needle. The anterior wall and sphincteric area are rarely involved, usually only in diffuse or inoperable cases.

Flat, infiltrating tumors, which so readily recur, are treated at the Mayo Clinic with radium emanation prior to operation. Small amounts of the element are used with the idea, not of completely destroying the growth, but of diminishing the capacity of the cell for proliferation.

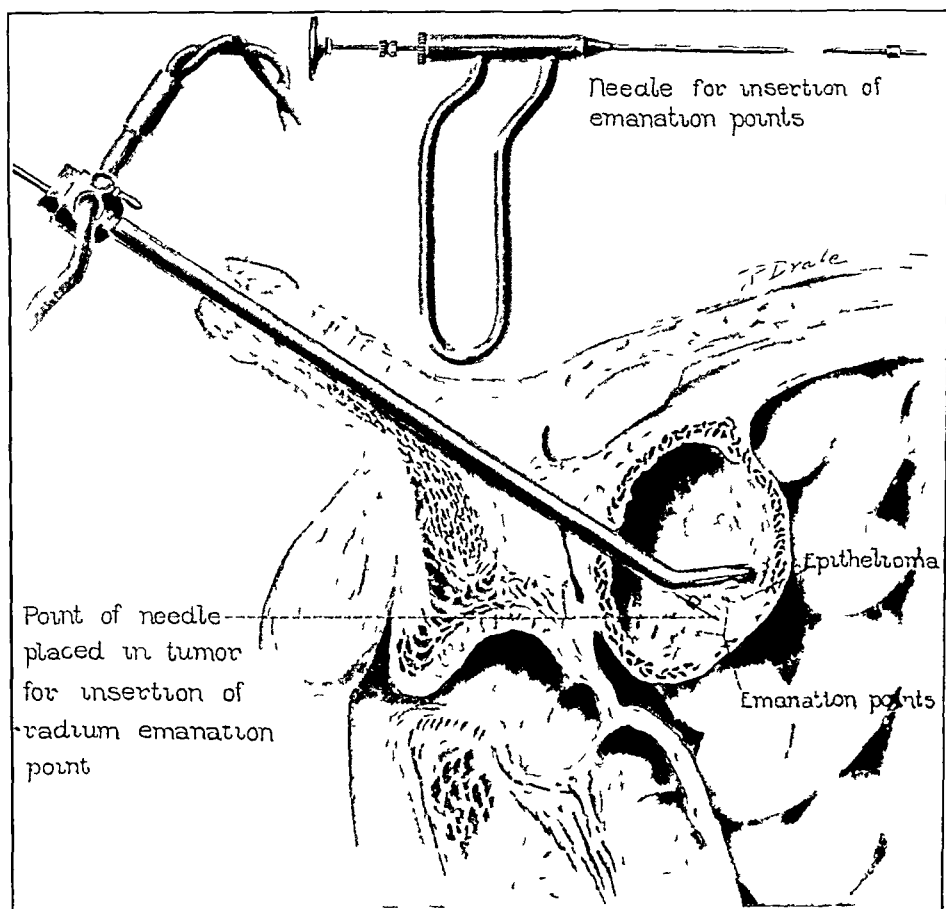


Fig 1—Application of radium emanation points through the Braasch direct vision cystoscope

This is done in an attempt to inhibit early recurrences from segments not removed and to prevent reimplantation of cells freed during the excision of the tumor.

The patient is given a cystoscopic examination with a direct vision instrument, the basal opening of the cystoscope is placed on the tumor and the eye-piece detached. This allows the water free exit, following which the contraction of the bladder firmly implants the tumor against the open end of the instrument and holds it in place until the point

of the radium needle can be inserted and the tube driven into the growth. The bladder is then refilled with water and a second area of the tumor localized. This procedure is repeated until the tubes of emanation have been studded throughout the growth, on an average of about one to every square centimeter of tumor tissue. Tubes containing approximately 1 millicurie have been found the most satisfactory (Figs 1 and 2).

The case histories reported illustrate the technic, indicate the amounts of radium used, and record the immediate results obtained. Sufficient time has not elapsed since the patients were first treated to

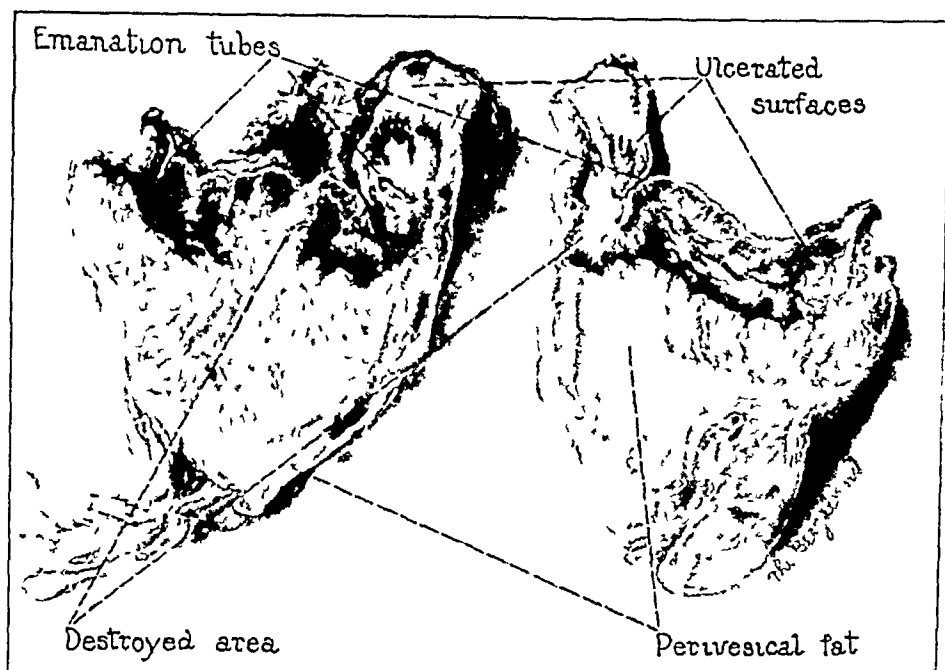


Fig 2 (Case 1) —Resected carcinoma of the bladder, areas of destruction around the radium emanation tubes

justify any statement concerning the efficiency of the treatment. It is not held that these changes result from the action of radium rays alone, but merely that they are a sequence of radium irradiation.

#### REPORT OF CASES

CASE 1 (A 352196) —J. McL., man, aged 63, came to the clinic in March, 1921, with a complaint of intermittent pyuria and occasional hematuria during a period of ten years. During the eight months before examination, he had lost 14 pounds (6.4 kg.).

Cystoscopic examination revealed a flat, irregular mass, 2.5 by 4 cm., on the posterior wall of the bladder. A specimen was removed for examination and 800 mg. hours of radium emanation in six tubes was inserted in the tumor. The removed portion proved to be papillary carcinoma. The cells were regular in outline, but varied in size and shape.

At operation twenty days later, a small, fibrous, ulcerated epithelioma was resected from the posterior wall. The suprapubic wound healed completely in ten days.

Histologic examination of the tumor removed at operation revealed extreme fibrosis. The bulk of the growth was composed of necrotic and fibrous tissue with numerous thin-walled, newly formed blood vessels. A number of emanation tubes were found still embedded in the tumor, around several of which necrosis extended for a distance of 8 mm. The few malignant cells found were extremely large and granular, a number of them showing extensive hyaline degeneration. The whole structure gave evidence of an intensive reaction. Some cells were small, with pyknotic nuclei, others were extremely large, newly formed, and atypical (Figs 3, 4 and 5).

CASE 2 (A 369414)—W. A. N., man, aged 57, came to the clinic in August, 1921, on account of intermittent hematuria, of two years' duration.

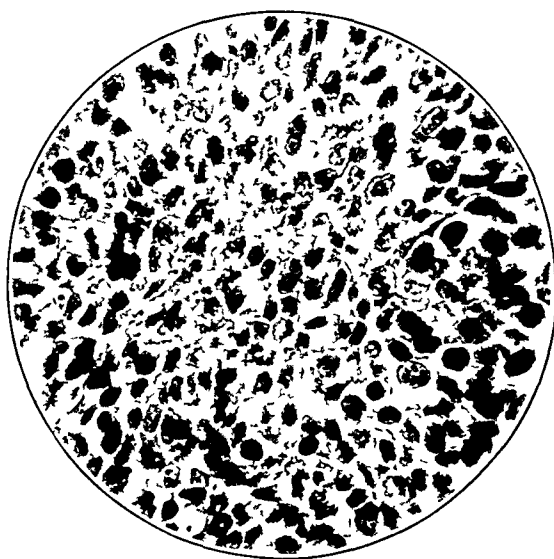


Fig. 3 (Case 1)—Epithelioma before radium treatment,  $\times 350$

Cystoscopic examination revealed an area, 2 by 2 cm, on the right base. The growth was flat and meaty, with an irregular surface. A portion of the tumor was removed for examination and 900 mg hours of radium emanation in eight tubes was inserted. The specimen revealed papillary carcinoma, the malignant cells were packed solidly together with only a small amount of intervening stroma, the nuclei were large, irregular and prominent, and a moderate number of mitotic figures were found (Fig 6). A second cystoscopic examination fifteen days later showed that the mass practically had disappeared.

At operation, September 12, an ulcer 4 cm in diameter was excised from the bladder wall, which was markedly edematous around the lesion. The excised ulcer showed only inflammatory tissue, no evidence of malignancy was found.

CASE 3 (A 355403)—F. K. O., woman, aged 47, came to the clinic in April 1921, complaining of intermittent frequency and dysuria of ten years' duration. Since 1917, the urinary trouble had been almost constant and she had lost 50 pounds (22.7 kg) in the last year.



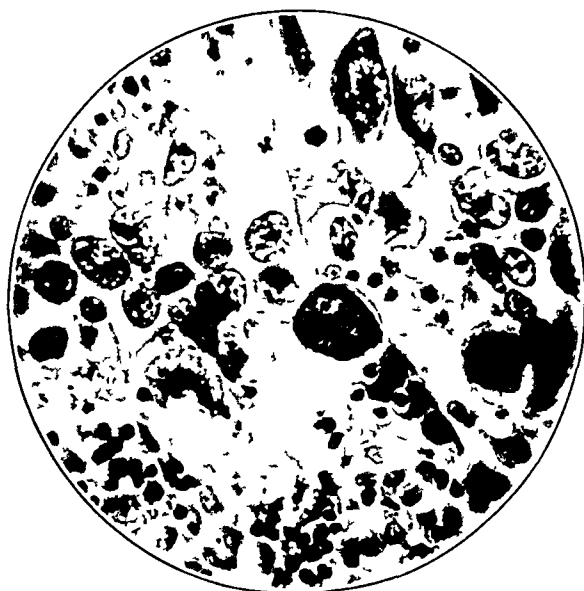


Fig 4 (Case 1) —Epithelium after radium irradiation, enormously enlarged cells,  $\times 350$

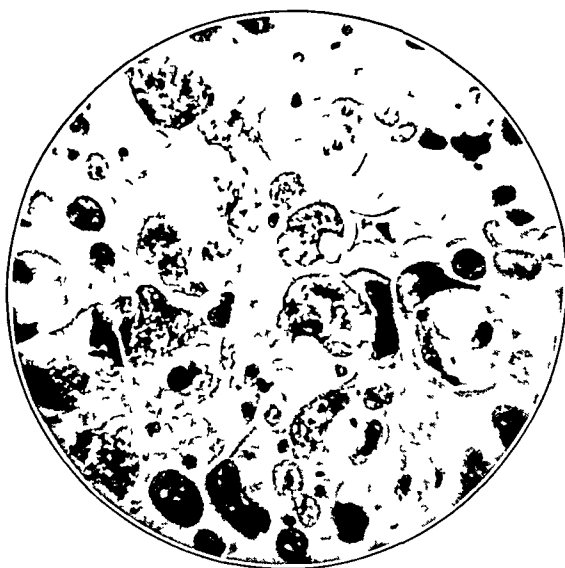


Fig 5 (Case 1) —Epithelioma after irradiation, enlarged cells, vacuolization, hyaline degeneration and atypical mitotic figure,  $\times 350$

Cystoscopic examination revealed two solid tumors on the right side of the bladder, one 4 cm and the other 2 cm in diameter. Six tubes containing 1,600 mg hours of radium were inserted in the growth. For several days after the insertion of the radium tubes, the dysuria increased and a number of shreds of tissue were passed.

At operation, seventeen days later, a flat ulcerated area, 3 cm in diameter, was found on the right wall and base of the bladder, involving the ureteral orifice and penetrating to the peritoneum at one point. The area was completely excised, including 5 cm of the ureter. The remaining portion of the ureter was tied and dropped back into the wound. The section removed was markedly ulcerated and fibrous. Several emanation tubes were found surrounded by areas of necrosis and fibrous tissue about 1.5 cm in diameter.

On histologic examination, the growth was found to consist of enormous malignant cells, most of which were undergoing granular degeneration. The

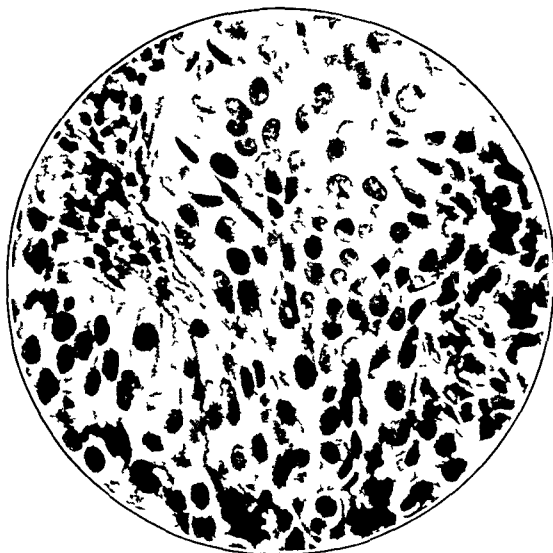


Fig 6 (Case 2)—Epithelioma before irradiation, no evidence of malignant cells found at operation after having been treated with radium,  $\times 350$

majority of these cells were from five to six times larger than nonirradiated cells, many of them contained large vacuoles. The increase in the connective tissue elements was only slight in comparison with the fibrous overgrowth noted in the other cases (Fig 7).

CASE 4 (A 355232)—D C, man, aged 64, came to the clinic in April, 1921, with a history of urinary frequency of three years' duration, and almost constant dysuria, with attacks of hematuria of one year's duration.

Cystoscopic examination revealed a mass, 4 cm in diameter on the right wall of the bladder, involving an orifice. The growth was flat and firm and covered with stubby protrusions. One thousand milligram hours of radium emanation in five tubes was inserted in the growth. On the fourth and fifth days after the insertion of the radium, the patient felt drowsy and had little appetite. Several days later a number of pieces of necrotic tissue were passed with the urine.

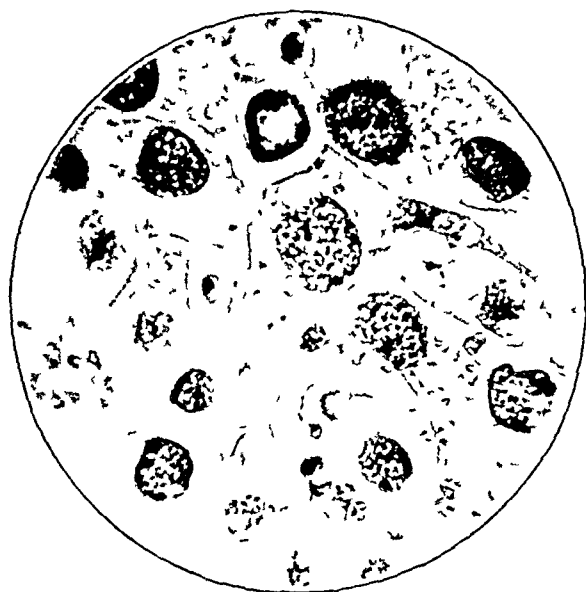


Fig 7 (Case 3) —Greatly enlarged cells undergoing granular degeneration as a result of radium irradiation,  $\times 350$

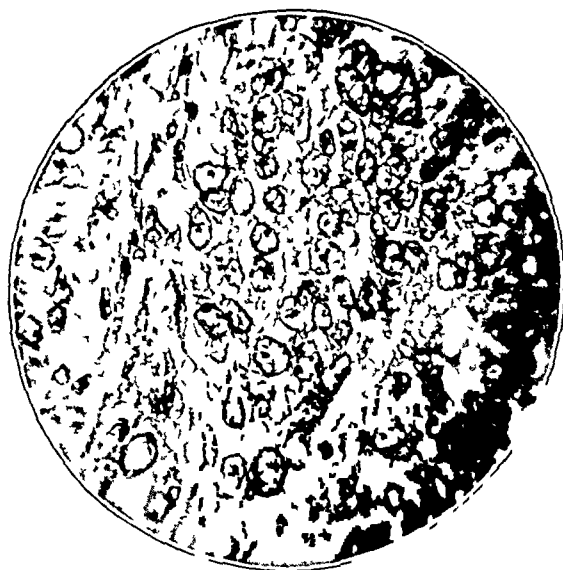


Fig 8 (Case 5) —Distinct cellular outlines with destruction of nuclear substance following radium irradiation,  $\times 350$

At operation nineteen days after the insertion of the radium, a small knotted extremely fibrous mass with a necrotic surface was removed. The growth involved the right ureter which was ligated and cut. There was a definite radium scar directly above the growth, possibly the normal mucosa had approximated the tumor and radium emanations at this point when the bladder was empty. The excised area was shrunken, black, and fibrous. Three empty emanation tubes were found in the tumor.

Histologic examination revealed almost complete fibrosis, and in several areas, especially around the tubes necrosis. In a few areas, there were definite nests of unchanged malignant cells, well walled off with fibrous tissue.

CASE 5 (A 357784)—M. K., woman, aged 64, came to the clinic in September 1921, on account of an almost constant hematuria and dysuria of nine months' duration.

Cystoscopic examination revealed an extensive irregular tumor involving the left wall of the bladder and the left orifice. Seven hundred and fifty milli-



Fig. 9 (Case 5)—Condition following radium irradiation: marked edema of a highly cellular epithelioma,  $\times 100$ .

gram hours of radium in five tubes was inserted in the growth under sacral anesthesia.

Twenty-two days later a tumor completely involving the left wall was resected. The left ureter was ligated and cut, and the renal portion left in place. Convalescence was satisfactory. The tumor, which measured 2 by 4 cm., was flat with a firm ulcerated surface.

Histologic examination revealed epithelioma. The tumor was markedly edematous with only a moderate round-cell infiltration. Connective tissue reaction was very slight, and the enormous atypical cells seen in other irradiated tumors were absent. Most of the cells retained their regularity of size and outline, but there was widespread destruction of the nuclei which were small and shrunken in some areas. In most sections, however, the malignant cells were recognized merely by their outline, as the nuclei were not visible (Figs. 8 and 9).

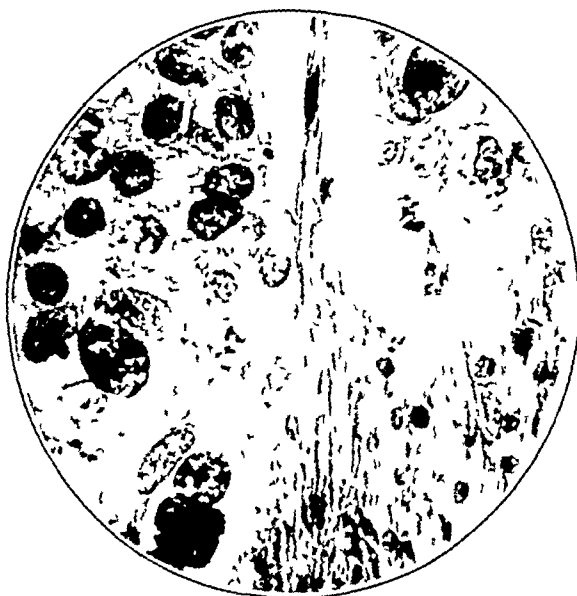


Fig 10 (Case 6) —Wedge of fibroblasts separating groups of enlarged degenerating cells, following radium treatment,  $\times 450$



Fig 11 (Case 6) —Extreme fibrosis, splitting up and isolating areas of degenerating cells, following radium treatment. The malignant cells are greatly enlarged, and becoming hyalinized in places,  $\times 80$

CASE 6 (A 356999)—F A S, man, aged 67, came to the clinic in April, 1921, on account of dysuria and hematuria which had been almost constant for six months

On cystoscopic examination, a meaty, circumscribed tumor, 3 by 3 cm in diameter, was found on the right wall, surrounded by an area of bullous edema. The growth was flat and circumscribed, and involved the right orifice. Under sacral anesthesia, a specimen was removed and nine radium emanation tubes totaling 1,100 mg hours were planted in the growth approximately 1 cm apart. Histologic examination of the specimen revealed papillary epithelioma of a high degree of malignancy. The cells were irregular in size and shape, matted together with only a small amount of connective tissue, and contained a moderate number of mitotic figures.

At operation nineteen days later, a mass 2.5 cm in diameter was resected from the bladder, with the right ureteral orifice and 3 cm of the right ureter. The renal portion of the ureter was ligated and dropped back into the wound. The specimen removed at operation was shrunken and hard. Microscopic sections showed extensive fibrosis with many areas of exceptionally large malignant cells as much as three or four times the size of those found in the section removed before irradiation. These large cells generally showed granular or hyaline degeneration, with an occasional markedly atypical mitotic figure. Numerous small malignant cells with deeply staining shrunken nuclei were seen. In some areas, fine strands of fibroblasts passed between the malignant cells, in others, thick, fibrous bands, which often followed the connective tissue remnants of altered papillae, divided the tumor into isolated islands of malignancy (Figs 10 and 11).

#### COMMENT

The most striking feature of irradiated tumors is extreme fibrosis which produces extensive walling off, replacement, and destruction of the tumor cells. This is preceded by extensive vascularization. The malignant cells often showed remarkable changes, including many unusual division forms, and marked hyaline and granular degeneration, the majority were obviously incapable of further growth.

In some cases, the radium rays undoubtedly completely destroyed the proliferating power of the cells, but, in a number of tumors, nests of apparently intact malignant cells were found. These cells, generally walled off by extreme fibrosis, were, as a result of the exposure to radium rays, apparently quiescent at the time of operation. Later, when the reaction from irradiation had subsided, they undoubtedly would have become active again. The reactivation of these isolated cells might well explain the late recurrences of tumors clinically cured by radium. On this account, it is advisable to carry out complete surgical removal of the tumor-bearing area. Frankl and Amreich<sup>13</sup> found that radium and roentgen rays exert a profound influence on malignant cells as long as forty days after exposure, cells not completely destroyed

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<sup>13</sup> Frankl, O., and Amreich, I. The Histologic Changes Incident to Radium and X-Ray Treatment of Uterine Carcinoma, Surg., Gynec. & Obst. **33** 162-163 (Aug.) 1921.

showed various forms of degeneration. After a certain period, the effect of irradiation subsided, and areas were found in which the cells again proliferated rapidly and resembled those present before irradiation.

Surgical procedures should be carried out about two weeks after the insertion of the radium tubes. If delayed longer, there is fusion of the normal cleavage planes and extensive edema of the bladder wall that increase the technical difficulty of the operation. The desirable fibrosis and walling off of tumor tissue does not occur until eight or ten days after irradiation.

The insertion of tubes of radium emanation is a simple procedure which may be done at the time of the first examination. The small amounts of radium rays are slowly discharged, and very little reaction is produced. The emanation tubes give off only about 16 per cent of their energy daily. Most tumors of the bladder are superficially placed, thrombosis of the blood vessels develops early and there is consequently only a slight absorption of necrotic or toxic substances. The bulk of the growth sloughs off and is passed with the urine. In several cases, a few days of general malaise with a slight increase of symptoms followed irradiation.

During the period between the insertion of the radium emanation and the operation, the patient is given a daily bladder lavage, which not only removes any necrotic slough but also reduces infection of the bladder, which is often present. This preliminary washing limits the absorption of toxic substances as do drainage and lavage of the bladder prior to prostatectomy. An uneventful convalescence is insured and the septic complications which occasionally occur after bladder operations are prevented.

Radium has not infrequently been used following operations for bladder tumors, but this practice is complicated by disadvantages which are not present in preoperative irradiation. In areas recently operated on, radium rays destroy the newly formed capillaries and prevent normal tissue healing. Following a resection, the distortion of the bladder walls makes it impossible to use radium emanations or to apply accurately a capsule containing the radium salt to the involved area. When used in the contracted bladder after operation, the radium salt occasionally produces lesions of the normal mucosa which are extremely painful and of long duration.

Emanation tubes were used also in several cases of malignant papilloma, but without satisfactory results. Because of the loose structure of these tumors, the tubes were not retained in place a sufficient length of time to be effective. In the majority of cases in which the emanation tubes have been used, the patients have been of advanced age, with widespread, highly malignant growths requiring extensive operations.

The efficiency of this procedure of preoperative irradiation will be determined only after several years, by comparison of this group of cases with a similar group requiring the same extensive operative interference. At present, it offers an easily applied, effective method of radium irradiation that does not reduce the resistance of the patient or increase the technical difficulties of a complete surgical removal of the tumor-bearing area.

#### SUMMARY

Radium rays administered in small amounts definitely destroy the proliferative power of living cells. The activity of the cell is lessened, and it passes through a quiescent stage from which it gradually recovers as the effects of the radium wear off. In many cases, there is destruction of the nuclei which is accompanied by an atypical cell growth and vascularization, and later by fibrosis.

At the Mayo Clinic, the flat, infiltrating, rapidly recurring type of bladder tumor is exposed to radium before operation in an effort to reduce the activity of the malignant cells and prevent operative transplants and early postoperative recurrences. Tubes of radium emanation are inserted through the direct cystoscope into the substance of the tumor, which later is removed surgically. Specimens for histologic study are removed from the tumor before irradiation, and their histologic structure is later compared with that of the surgically removed area. In the majority of cases, there is a marked reduction in the size of the tumor, with a widespread and constricting fibrosis.



# LEUKOPLAKIA OF THE KIDNEY PELVIS

HERMAN L KRETSCHMER, M D

CHICAGO

In a former paper on the subject of leukoplakia of the urinary organs, I<sup>1</sup> reported a case of leukoplakia of the bladder and lower end of the ureter. At that time, a careful review of the literature was made and a brief summary was given of the histories of forty-four cases that I was able to find in the literature at my command, making a total of forty-five cases.

During the past year, two publications have appeared in which two new cases were reported, one by Richey<sup>2</sup> of Pittsburgh and one by Marion<sup>3</sup> of Paris. Richey's case occurred in the kidney pelvis, and, in Marion's case, the bladder was the seat of this unusual change. Marion's case also showed the presence of epitheliomatous degeneration.

Several years ago, Pollack<sup>4</sup> reported a case of leukoplakia of the kidney and one of the bladder which were not included in my previous paper. These two reports, with the two cited and two cases about to be reported, make a total of fifty-one cases.

In my former paper the following conclusions were drawn:

- 1 Leukoplakia is a rare condition
- 2 The etiology is unknown
- 3 The histopathologic findings appear to be uniform and constant
- 4 There is no symptom or syndrome by means of which the condition can be diagnosed
- 5 The presence of large quantities of squamous epithelial cells in the urine from the bladder and from the kidney after ureteral catheterization, and the passage of pieces of membrane or flakes of squamous epithelial cells are very valuable findings in making the diagnosis

6 By means of careful cystoscopic examination, leukoplakia of the bladder can be definitely recognized.

The first case of leukoplakia of the kidney pelvis herewith reported came under observation, Sept 21, 1920. A nephrectomy was performed for a right-sided renal tuberculosis. The presence of leukoplakia was not discovered until after the removed kidney was cut open and the pelvis exposed.

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1 Kretschmer, H. L. Surg, Gynec & Obst **31** 325 (Oct) 1920

2 Richey, DeW. G. J. Lab & Clin Med **5** 635 (July) 1920

3 Marion, G. J. d'urol **9** 257, 1920

4 Pollack. Beitrage zur Metaplasiefrage, Wiesbaden, 1901, Ueber Knochenbildung in der Lunge, Virchows Arch f path Anat **165** No 1

## REPORT OF CASES

CASE 1—*History*—Mrs G, aged 40, three years before coming under observation was operated on because of bladder distress. A tumor was removed from the right ovary and half of the left ovary was removed. The symptoms were not relieved by this operation.

Three weeks ago the patient was subjected to cystoscopic examination elsewhere, and a diagnosis of multiple ulcers of the bladder was made. The onset occurred about four years ago, with practically constant symptoms. Following the operation there was some relief of symptoms for about two months. The patient voided about every hour during the day and five or six times in the early part of the night, and then at longer intervals as the night progressed. The pain was located in the bladder and was present during and after urination, being worse when the bladder was full. It was aggravated when the patient was on her feet and was relieved by rest and alkaline treatment. Urgency had been present ever since the onset of trouble. If the patient did not have the opportunity to void immediately on having the desire, the urine escaped. This was because the pain in the bladder became so intense that she seemed to lose control. Shortly before operation, the patient noticed clots of blood in the urine, but no blood was ever seen until about two months ago, when the urine was red and contained clots. Tenesmus has been present since the onset of symptoms. Long shreds of fleshlike material were occasionally seen in the urine.

## RESULTS OF URINE EXAMINATION

	Cell Count	Cultures	Urea	Tubercle Bacilli
Bladder	70 cells	Staphylococci	0.25	Positive
Right kidney	520 cells	Sterile	0.4	Positive
Left kidney	Red blood cells	Sterile	0.45	Negative

*Examination*—Roentgen-ray examination was negative for stone in the kidneys, ureters and bladder. Cystoscopic examination, Sept 23, 1920, revealed a bladder capacity of 2 ounces (59.2 cc). Cystoscopy was very painful. Near the air bubble was seen an area of superficial ulceration surrounded by a zone of hyperemia. Adhering to the surface of the ulcer was a shred. On the posterior wall, a similar ulcer was seen. The ulcers were about half the size of a finger nail. The right ureteral orifice was slightly edematous, and a great deal of difficulty was experienced in passing the catheter up the right ureter. Five catheters were used and all stopped 1 cm up. Finally a small No. 4 catheter was passed. Urine from the left side was clear, but in the urine from the right side there were a few specks.

*Operation*—Dec 9, 1920, under ether anesthesia, the usual right lumbar nephrectomy was performed. The patient made an uneventful recovery.

*Description of Gross Specimen*—The kidney was about normal in size and color. The capsule stripped easily, leaving a smooth regular surface, with the exception of two areas. One area about 2 cm in diameter, on the posterior superior aspect of the kidney, was very slightly sunken. It was of a darker color. On close observation, small yellowish or grayish tubercles the size of a pinhead, could be seen. There was a similar area, 1 cm in diameter, on the medial surface. Sections of these areas showed the cortical markings to be destroyed and the process to extend in a wedge-shaped mass down to

the calices. In it were a number of gray or yellowish hard tubercles, the size of a pinhead, from which tubercle bacilli were obtained on direct smear. The calices involved had lost their normal, smooth, glistening appearance, were very irregular and contained yellowish white elevations, varying in size from that of a pea to that of a pinhead. Otherwise the cortex and medulla appeared to be normal.

The upper part of the pelvis was normal and had a grayish white glistening appearance (Fig 1). On the lower part, about the ureteral outlet there was an area measuring 2 cm by 1.5 cm, extending down the ureter for 1.5 cm, very sharply demarcated from the rest. It was of a slate or bluish-gray color, becoming purplish down the ureter, where it abruptly ceased and normal ureteral lining began. The borders were sharply outlined but very slightly elevated. The surface was rough, thrown into irregular folds, and on it were collections of cells resembling cholesteatomas. The ureter was not thickened or hardened.

*CASE 2—History*—L. B., a man, aged 26, entered the United States Veterans' Hospital No. 76 complaining of pain in the bladder region, hematuria, frequency, urgency, tenesmus and pain in the right side of the abdomen in the region of the right kidney. The present illness began in 1918, following an attack of influenza while in service in France. At this time, some clots of blood were noticed in the urine, this condition lasting for several days. At the time of admission to the hospital, bright red blood was present at the end of urination. Pain in the right side of the abdomen was of a dull aching character and generally it was relieved by taking a cathartic. These attacks of pain occurred once or twice a month and lasted for three or four days.

*Examination*—Physical examination was negative. Roentgenograms showed the right kidney outline low and apparently very much larger than normal. The outline of the upper pole was not seen in the roentgenogram. No stone shadows were present. Cystoscopic examination revealed no signs of stones or tumor. Near the apex of the bladder was an area of ulceration surrounded by a zone of hyperemia. The surface of the ulcer was covered by a slough. There was a second similarly shaped ulcer behind the right ureteral orifice. Ureteral orifices were normal and were easily catheterized. Specimens of urine obtained from the right and left catheters were sterile on culture. A few pus cells were noted in the urine from the left kidney. Examinations of the urine for tubercle bacilli were negative. The phenolsulphonaphthalein test showed an output of 41 per cent from the right kidney in two hours and 36 per cent from the left kidney. A pyelogram revealed the presence of a large hydronephrosis on the right side.

*Operation*—Feb. 25, 1922, the usual oblique lumbar incision was made over the right kidney area. Delivery of the kidney was difficult because of the short pedicle and the large size of the hydronephrotic kidney. The pelvis was isolated, the ureter was divided at the pelvic brim and the kidney was removed.

*Postoperative Course*—Ten days after operation the patient developed phlebitis of the left leg.

*Description of Gross Specimen*—The specimen consisted of a large hydronephrotic kidney, about 7 inches (17.8 cm) long, the surface of which was irregular. The pelvis was 2¾ inches (7 cm) wide and 3½ inches (8.9 cm) long. The ureter and pelvis of the kidney were opened, the mucosa was normal. In the posterior wall of the kidney pelvis was seen an area two-thirds inch (17 mm) long and one-fourth inch (6.4 mm) wide which stood out in marked contrast to the rest of the kidney pelvis. It was dull white and presented a



Fig 1—Large area of leukoplakia in the pelvis which passes down into the rectum where it comes to an abrupt stop



dry, lusterless appearance. The gross appearance was that of leukoplakia. The rest of the kidney showed an enormous amount of dilatation. A small piece was excised for histologic study. Examination demonstrated stratified squamous epithelial cells. This area of metaplasia occupied the posterior wall of the pelvis and was situated  $1\frac{1}{4}$  inches (3.17 cm) above the ureteral opening.

#### COMMENT

Metaplasia is the postnatal production of specialized tissues from cells which normally produce other kinds of tissues and is an adaptation, on the part of the cells, to an altered environment (Adami and McCrae<sup>5</sup>). It may occur either as a physiologic or a pathologic process. I am of the opinion that we are inclined to forget that metaplasia occurs as a physiologic process. As an example of this type of metaplasia may be mentioned the conversion of cartilage into bone, as well as the conversion of connective tissue corpuscles into fat cells. An important point to remember is that epithelial tissue can be transformed only into epithelial tissue and mesoblastic tissue only into other forms of mesoblastic tissue.

Heterotopia should not be confused with metaplasia, the former consisting of the abnormal snaring-off of cells of an organ from the organ proper and its subsequent growth in another place. Two forms of heterotopia are generally recognized—congenital and acquired. Aberrant suprarenals and accessory spleens may be mentioned as congenital types, and bony growths from displaced periosteum as examples of the acquired types. Therefore, in heterotopia there is no transformation of tissue.

Likewise, metaplasia should be differentiated from heteroplasia, which, according to Adami and McCrae, is the condition in which we find, in the middle of the esophagus, normally lined by squamous epithelium, islands of columnar epithelium, similar to epithelium in the stomach. No conversion has occurred from one type of epithelium into the other, there is merely a persistence of misplaced tissue.

Another condition which lies outside the discussion is the growth of one tissue to push back the normal tissue and to replace it. According to McCallum, this occurs, for example, when the skin about a healing tracheotomy wound grows through the opening and extends inward, so as to line the trachea for a short distance. I once saw this occur in the urinary bladder in which a suprapubic fistula had been present for several years.

Many are the views that have been advanced from time to time to explain the occurrence of metaplasia, but the real etiology of this condition is unknown. The presence of calculi in the bladder in a

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<sup>5</sup> Adami, J. G., and McCrae, John. *Textbook of Pathology*, Philadelphia, Lea & Febiger, 1912, p. 202.

few of these cases has led a number of authors to believe that stone may be a factor in the causation of the condition, despite the fact that stone is not always found in these cases. Again, there are innumerable cases of bladder stone which have never shown the presence of leukoplakia. The idea advanced is that a stone or foreign body produces irritation and that irritation in turn results in leukoplakia. Attention has also been directed to similar plaques in the mouth that are often encountered in pipe smokers, and it is believed that they, too, are due to irritation.



Fig 2—Large amounts of desquamated squamous cells adhering to the surface of the mucosa of the pelvis of the kidney, the submucosa showing round cell infiltration

Lecene is not inclined to believe that chronic inflammation is responsible for this condition. He thinks that the lesion is congenital, owing to disturbances in the development of the urinary apparatus. He states that embryologically it is easy to explain heterotopia of the ectodermic cells in the vicinity of the mucosa of the upper urinary passages, and the fact that this may occur is sufficient to account for the lesions of leukoplakia.

Halle asserts that chronic inflammation, simple or calculous, may produce an epithelial transformation in the mucosa of the urinary tract, the normal covering being transformed into stratified pavement epithelium with epidermic characteristics

The same authority in reporting his cases states that study shows the influence of chronic inflammation in the etiology of epithelial transformations, for, with few exceptions, these patients have an old cystitis, or a ureteropyelitis and cystitis due to gonorrhea, stricture or



Fig 3—Stratum granulosum above which are seen the lamellae of desquamated squamous cells

prostatic disease, or a postpuerperal cystitis due to catheterization, especially in cases in which the condition has been tenacious, and rebellious of treatment

Lichtenstern mentions as etiologic factors, long-continued inflammation, foreign bodies, stones, tuberculosis, etc

Posadas believes that leukoplakia, in most instances, offers a pathologic condition, the origin of which may be traced back to syphilis, and when this is found, the benefit from specific treatment is unquestionable. He is of the opinion that if we do not obtain satisfactory results with the usual methods of treatment when it is a matter of



a decided vesical affection with febrile hematuria and the throwing off of purulent mucosa, we should try mercurial treatment before proceeding to suprapubic cystotomy

That leukoplakia of the kidney pelvis may have a congenital origin has been mentioned, and to illustrate this fact, the case of Leber has been repeatedly cited. Leber's case, it will be recalled, occurred in an infant 4 months old, in whom, besides leukoplakia of the kidney, there was also leukoplakia of the eye

Wells<sup>6</sup> states that in metaplasia we have what may be interpreted as a chemical alteration due to mechanical stimuli, that is, the formation of keratin by cells which ordinarily do not form it

Cases of metaplasia occurring outside the urinary tract have been reported by various observers. Haythorn<sup>7</sup> has reported a case of primary carcinoma of the lung, arising in a bronchus. The lower layer of cells remained columnar in type, while the more superficial layers were composed of typical stratified squamous cells. A case of stratified squamous-cell carcinoma of the lung with cornification was reported by Cohn.<sup>8</sup> Typical pearls were formed in sections of this tumor

In discussing the question of metaplasia, Lewisohn<sup>9</sup> reported two cases of unusual carcinoma, one of the uterus and one of the pancreas. He considers the question as to whether there is a real metaplasia of epithelium, and says: "It is conceivable that a typical pavement epithelium cancer of the uterus might originate without such a metaplasia, since it is not far from the pavement epithelium of the portio vaginalis, hence there might be a displacement, or even an extension of this pavement epithelium to the uterus. But this explanation will hardly hold in the case of tumor of the pancreas, since the pancreas does not lie near any tissue of ectodermal origin."

Cases in which metaplasia occurred in the epididymis have also recently been reported by Cunningham and Ohmori

#### ASSOCIATED KIDNEY PATHOLOGY

Various associated pathologic conditions have been found in the kidneys. In one case described in this paper, there was an early renal tuberculosis with tuberculosis of the bladder. Tuberculosis of the kidney was also found in Beer's case, as well as in the case reported by Beselin. In my second case there was a large hydronephrosis

Renal calculus with leukoplakia has been reported by Halle, Chiari, Pollack<sup>4</sup> (Lubarsch's case), and in Ronas' case, there were stones in the pelvis and ureter of the opposite side

<sup>6</sup> Wells, H. G. *Chemical Pathology*, Philadelphia, W. B. Saunders Company, 1918, p. 285

<sup>7</sup> Haythorn. *J. M. Research* **26** 523, 1912

<sup>8</sup> Cohn, quoted by Lewisohn. *Ztschr. f. Krebsforsch.* **3** 528, 1903

<sup>9</sup> Lewisohn. *Ztschr. f. Krebsforsch.* **3** 528, 1903

In Lecene's case, there was a large infected kidney with retention. One of Ronas' patients had a purulent perinephritis, and in Brik's case, there was an associated interstitial nephritis.

#### DISTRIBUTION

From a review of these cases it would appear that in leukoplakia involving the urinary organs, the bladder is most frequently affected. This is evidenced by the fact that in thirty of the reported cases, the bladder was the seat of the pathologic condition, and that in only twelve cases were the kidneys found to have this lesion. In three cases, the ureter was affected.

Various combinations of distribution are also to be noted: bladder, one kidney and one ureter, 1 case; bladder, one kidney and both ureters, 1 case; bladder, two kidneys and two ureters, 1 case; urinary tract, 1 case; one kidney and one ureter, 1 case; and bladder and ureter, 1 case.

#### RELATIONSHIP TO CARCINOMA

The entire subject of metaplasia and leukoplakia is interesting from three points of view: (1) as to the various theories that have been advanced from time to time regarding the exact method of origin, (2) as regards the various etiologic factors which supposedly produce or aid in producing this condition, and (3)—not the least—the relationship that exists between leukoplakia and carcinoma, a possibility that has been repeatedly pointed out in cases of carcinoma of the mouth developing from these plaques.

The presence of stratified squamous cell carcinoma occurring in organs which normally do not contain this type of epithelium is generally explained on the basis of metaplasia of the normal epithelium of these organs into stratified squamous epithelium and the formation of leukoplakia, with subsequent carcinomatous degeneration of these patches or plaques.

To conclude, it may be stated, with a considerable degree of probability, that stratified squamous-cell carcinoma of the kidney and bladder can be explained on the basis of metaplasia with leukoplakia formation.

# PRIMARY SQUAMOUS-CELL CARCINOMA OF THE KIDNEY AS A SEQUEL OF RENAL CALCULI \*

H GIDEON WELLS, M D

CHICAGO

An unusual case of renal tumor that has recently come under my observation carries so much evidence as to the relation of trauma and tumor formation, as well as to other problems of pathology, that it seems worthy of publication. It concerns a case of primary squamous-cell carcinoma of the kidney, arising as a sequel of renal calculi.

## REPORT OF CASE

*History*—A man, aged 57, a tailor, entered the Cook County Hospital, June 13, 1921, two weeks before his death, complaining of abdominal pains of six months' duration, associated with frequent burning micturition, and a loss of about 30 pounds (13.6 kg) in weight. There was no history of pain characteristic of renal colic, although he said that he had suffered from pain over the bladder when he was 20 years old, beyond this there had been no previous illnesses. Venereal infection and alcoholism were denied. He had never noticed blood in the urine, although it was turbid.

*Examination*—The only positive findings on examination were these. On the right side of the abdomen there was a tender mass about the size of a coconut, extending from the costal border to 5 cm above the umbilicus. Roentgen-ray examination revealed the presence of multiple stones in an enlarged right kidney. The cystoscope showed the vesical mucosa congested without ulceration. Ureteral catheterization showed that the right kidney did not function. With 1 cc of phenolsulphonephthalein, injected intravenously, the dye showed in the urine from the left ureter in six minutes, but none appeared from the right side in thirty minutes. The phenolsulphonephthalein test, intravenously, yielded 30 per cent in the first half hour and 20 per cent more in the second half hour from the left side. The urine contained albumin, pus, and blood, but few casts. A 25 per cent solution of sodium bromid was injected by the ureteral catheters, the right side taking 20 cc, the left 10 cc. Roentgenograms then revealed, on the left side, a somewhat enlarged left kidney with slightly enlarged multiple calices, the right kidney showed a pelvis of irregular shape, apparently with escape of the injected fluid into the substance of the diseased kidney. The stones seemed to be not only in the kidney but also in the surrounding soft tissues.

Blood analysis gave the following figures: total nonprotein nitrogen, 39.27 mg per hundred cc, urea nitrogen, 18.4 mg, uric acid nitrogen, 2.27, creatinin nitrogen, 1.47. The leukocyte count was 11,800.

Following the ureteral catheterization the patient had a chill, and he continued to grow progressively weaker, usually with a subnormal temperature. On June 28, under local anesthesia, the right kidney was opened and three large

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\* From the Department of Pathology, University of Chicago, and the Otho S. A. Sprague Memorial Institute.

dendritic cauli each about 3 cm in diameter were removed, together with large amounts of pus. The patient continued to sink, and died the next day, a postmortem examination being made about six hours after death.

*Necropsy Findings*.—The body was that of a medium sized man, with white skin showing no icterus. The superficial lymph glands were not enlarged. There was a recently sutured wound about 11 cm in length, in the back, below and parallel to the right twelfth rib. There were no other external abnormalities.

*Abdominal Cavity*.—There was 1 cm of subcutaneous fat in the midline. The mesenteric lymph glands were not enlarged. The lower pole of the left kidney extended slightly below the crest of the ilium. The peritoneal cavity was free from fluid and its surface was smooth and shiny. A tumor mass at the site of the right kidney extended to the anterior axillary line. The colon extended over and in front of the renal mass and was attached to the liver and mass by dense fibrous adhesions. A white nodule, 1 cm in diameter, which resembled a neoplasm was removed from the peritoneum in this region. When this was cut, it exuded a white, necrotic, softened material. There were no adhesions about the spleen or gallbladder.

*Chest Cavity*.—There were no abnormalities. The mediastinal glands were not enlarged.

*Heart, Aorta and Vessels*.—The heart was large in proportion to the weight of the body, weighing about 350 gm. The coronary vessels and their orifices were normal. There was no fibrosis of the myocardium. All valves were normal. The ascending aorta showed a few small yellow streaks which were more numerous in the arch than in the abdominal aorta. The lymph glands around the abdominal aorta were enlarged and continuous with the right kidney mass. The inferior vena cava was free from thrombi and compressed somewhat with lymph glands but it was not occluded. The left renal vein was compressed by lymph glands.

The trachea and esophagus were both normal.

*Lungs*.—The lower portion of the right lower lobe was slightly boggy and contained little air but there was no consolidation. There was an extensive calcification of one right peribronchial lymph gland. The weight of each lung was 400 gm. The lower lobe of the left lung contained small subpleural hemorrhages and a few small slightly consolidated areas over which the pleura was smooth and glossy. Yellow pus exuded from the bronchi in this region, together with a little fluid.

*Spleen*.—There were no gross changes.

*Liver*.—The liver weighed 2120 gm. The organ as a whole was enlarged, the surfaces were rounded, moist, swollen and soft in consistency. There was no increase in connective tissue. The gallbladder was normal in size and contained no concretions.

*Stomach*.—The stomach showed no gross abnormalities. Below the pyloric ring there were two pouches or diverticula, each about 1.5 cm in size, in the duodenal mucosa, with no evidence of inflammation or ulceration.

*Pancreas*.—This was normal.

*Kidneys*.—The left kidney was larger than normal, weighing 300 gm and measuring 11.5 cm long, 7 cm wide and 6 cm thick. The organ was soft, mottled and irregular in outline with a nonadherent capsule which was attached to the peritoneal tissue. The cut surfaces showed areas of marked disintegration, hemorrhage and softening with one abscess 2 cm in diameter, underneath the

capsule The cortex was 10 mm thick The pelvis showed no ulceration The ureters were of normal size and showed no ulceration but contained purulent material

The right kidney weighed 800 gm It measured 21 cm long, 13 cm wide and 7 cm thick, and it was adherent to the perirenal tissue which was indurated and contained several abscesses up to 3 cm in diameter The kidney was firmly adherent to the perirenal tissue over the entire surface, and about the pelvis, extensions of tumor growth had produced nodules and strands of neoplasm in the perirenal tissue itself The ureter was completely occluded at its junction with the pelvis, the lower portion of which was completely filled by masses of irregular cancer tissue, about 5 mm thick, surrounding the entire



Fig 1—Squamous-cell carcinoma of the renal pelvis,  $\times 60$ , showing the infiltration of the submucous tissues by carcinoma with formation of masses of keratin scales The lining of the cavity is formed by stratified epithelium

pelvis The cut section of the kidney disclosed a complete loss of all recognizable kidney tissue The organ consisted essentially of a mass of branching communicating cavities directly continuous with the pelvis, some of which extended to the capsule The surfaces were bathed with thick pus in which a few small remains of the original calculus were found Between the pus-filled cavities were masses of white cancer tissue with irregular necrotic surfaces, in places covered with blood clots The cancer tissue infiltrated through the renal capsule into the perirenal fat in many places The pelvic surfaces were

rough, but only occasionally was anything suggestive of a papillary character to be seen. In some places the shell of cancer tissue was only 1 or 2 mm thick, in others, masses from 2 to 4 cm thick remained. The kidney consisted practically of a pus-filled cavity formed by distention and ulceration of the renal pelvis, with walls composed entirely of cancer tissue. The portion of the stones obtained at the operation, together with the fragments found at necropsy, weighed 33 gm, air dried at room temperature. They constituted a typical dendritic calculus which had broken apparently spontaneously into three large fragments and four smaller ones. When fractured the surface was roughly crystalline. The external surface was lobulated, roughened, and showed some soft deposit on a harder central portion.

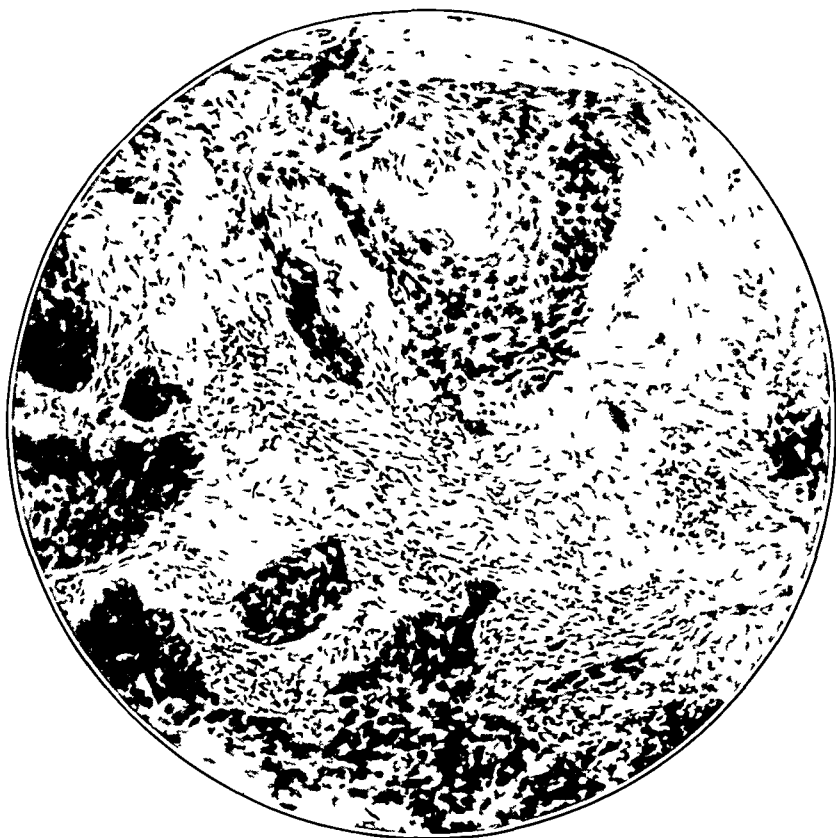


Fig 2—Squamous-cell carcinoma of the renal pelvis,  $\times 110$ . Higher magnification to show the resemblance to squamous-cell carcinoma of the skin.

The lymph glands around the kidney were enlarged, up to 5 cm in diameter, by white neoplastic tissue, with most of them showing suppurative softening.

**Suprarenals.** The left suprarenal was normal, the right was infiltrated with a white tissue, without much enlargement or nodule formation, apparently by direct extension from the kidney.

**Bladder.** The bladder contained a purulent material. The mucosa was hyperemic and contained much granulation tissue about the trigon together with many small hemorrhages but no ulceration or tumor growths. Both ureteral orifices and the urethral orifice were normal.

The prostate, seminal vesicles and testicles were normal

**Skeleton** No metastases could be found The vertebral column showed marked exostosis with complete ankylosis of many of the vertebral articulations

**Histologic Findings**—The white neoplastic tissue which replaced the right kidney and many retroperitoneal lymph glands, as well as the tumor nodule found in the peritoneum, consisted everywhere alike of typical squamous-cell carcinoma characterized by extensive formation of whorls of stratified keratinized epithelium It differed not at all from the keratinizing carcinomas that are found in the skin or mouth Nowhere were there structures resembling the ordinary papillary carcinomas of the renal pelvis, or the medullary transi-

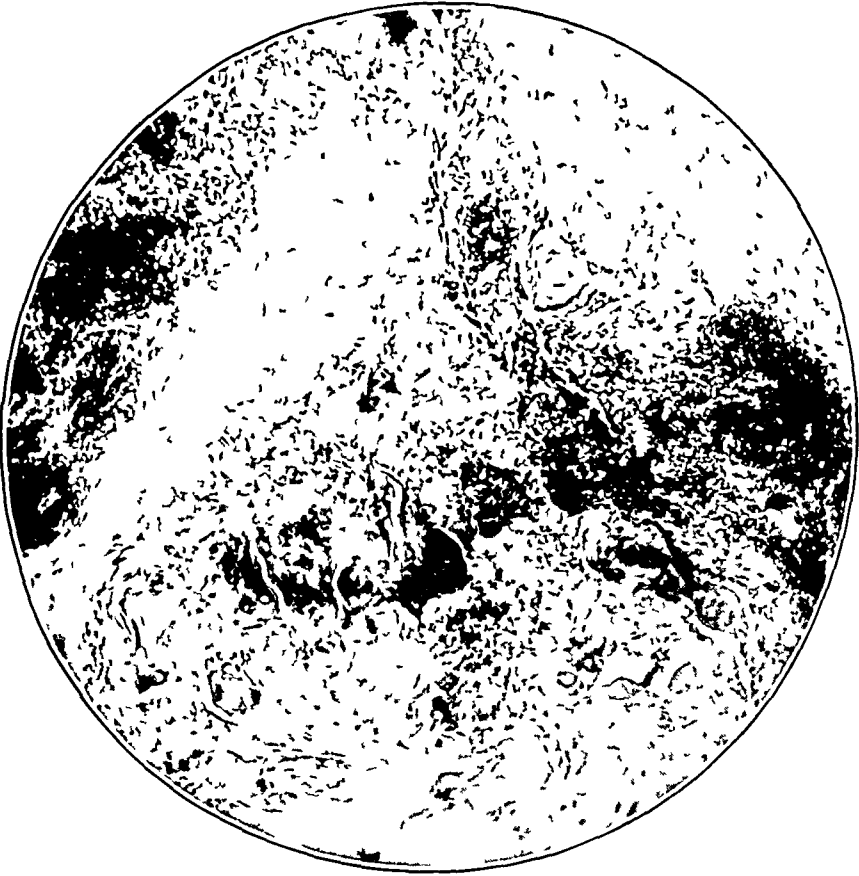


Fig 3—Metastatic squamous-cell carcinoma in a retroperitoneal lymph gland,  $\times 60$  Most of this field is occupied by masses of hornified epithelium

tional cell carcinomas In all parts of the tumor growth, both primary and secondary, there was acute suppurative inflammation In none of several sections examined were any remains of the kidney tissue to be seen The right suprarenal was partly replaced by carcinoma of the same type as that in the kidney

The left kidney showed only the usual changes of an acute ascending suppurative nephritis

No microscopic changes of present interest were found in the other organs

*Anatomic Diagnosis*—This was right nephrolithiasis, diffuse infiltration of the right kidney and perirenal tissues with squamous-cell carcinoma, acute suppurative pyelonephritis with complete destruction of the parenchyma of the right kidney, recent nephrostomy wound of right kidney with drainage, carcinomatous infiltration of right suprarenal, metastatic carcinoma nodule in peritoneum, secondary carcinoma and suppuration of retroperitoneal lymph glands, ascending suppurative nephritis of left kidney, acute cystitis and ureteritis, compression of inferior vena cava and left renal vein, hypertrophy of left cardiac ventricle, senile arterial sclerosis, moderate degree, atrophic pulmonary emphysema, calcified tubercle in a right peribronchial lymph gland, acute suppurative bronchitis and early hypostatic bronchopneumonia of left lower lobe, acute parenchymatous swelling of liver, and marked exostosis of the vertebral column

Samples of the renal stones were mixed together and analyzed for me by Miss Mary E. Maver, who obtained figures indicating an average percentage composition as follows

$\text{Ca}_3(\text{PO}_4)_2$ —70.70,  $\text{Mg}(\text{PO}_4)$ , 21.35,  $\text{CaCO}_3$ , 7.95

No oxalic acid, uric acid, xanthin or silicic acid was present

This is, then, a phosphate calculus, which is an unusual type of concretion to be found in the renal pelvis. There is a current statement in the literature to the effect that renal calculi are ordinarily composed chiefly of uric acid or urates, but more recent writers have reported that calcium oxalate is usually the chief component. Rowlands<sup>1</sup> found that twenty-two renal stones were composed almost entirely of calcium oxalate, phosphates were commonly present, and uric acid was absent or was found only in traces. Max Kahn<sup>2</sup> analyzed sixteen stones and found from 29.5 to 94.7 per cent of calcium oxalate, from 0.2 to 40.6 per cent of uric acid, from 2.1 to 56.2 per cent of phosphorus pentoxid, and no carbonate. Only two of these stones consisted chiefly of phosphate, and only two had much uric acid (40.6 and 23.6 per cent), while all but three had more than 70 per cent of calcium oxalate.

Such calculi as the one in this case, composed chiefly of a mixture of calcium and magnesium phosphate, ordinarily indicate the presence of long-continued ammoniacal decomposition of the urine. Under such cases these salts may precipitate on a previously existing urate concretion, and the urates in time may dissolve out and be replaced by phosphates, constituting the process of "metamorphosis" of calculi.<sup>3</sup>

1 Rowlands. *Biochem J* 3 346 1908

2 Kahn Max. *Study of the Chemistry of Renal Calculi*. *Arch Int Med* 11 91 (Jan) 1913

3 Wells H. Gideon. *Chemical Pathology*, Ed 4 1920 p 461



## DISCUSSION OF LITERATURE

The infrequency of tumors of this sort is indicated by the following statement made by Ewing<sup>4</sup> in his work on neoplastic diseases

Squamous-cell carcinoma of the pelvis was described by Kundrat in 1891 and later cases have been reported by Rundle, Graupner, Kischensky, Beisenbruch and Scheel. These remarkable tumors are usually of large size when discovered, but Battle observed squamous changes in a small villous tumor of the pelvis and Rundle found the upper ureter invaded by a squamous carcinoma of moderate dimensions. In other cases the pelvis has been distended and the wall infiltrated by a bulky growth. The kidney is either transformed into large cysts by hydronephrosis or infiltrated and destroyed. The squamous changes are very pronounced and much of the growth may be composed of epithelial pearls, many of which are hornified or calcified. In Schmorl's case, distant metastases showed the same structure. That the pelvic and ureteral epithelium is capable of extensive epidermization is well attested by the reports of Wendel of numerous cases of leukoplakia, usually associated with calculi. Rokitsansky described a very advanced condition, with much scale, desquamation, as "cholesteatoma." Ziegler found marked epidermization in pyelitis calculosa, and Beselm reported an advanced case with tuberculous pyelitis. Yet all cases are not associated with calculi or leukoplakia, so that the excessive hornification must be regarded as a tendency inherent in the growth.

In a case studied by the writer in a woman of 58 years, the kidney and tumor measured 14 by 19 cm. The tumor involved chiefly the extrapelvic fat but had occluded the lower half of the pelvis, along which it invaded the kidney. The renal cortex was thinned out over several large smooth-walled cysts. The ureter was destroyed down to the bladder. There were metastases in aortic and mesenteric nodes and in the uterus. The main bulk of this large tumor was composed of hornified and slightly calcified epithelial pearls surrounded by a moderate number of spindle or cubical granular epithelium. The transition from one to the other type of cell was very sharp.

Kaufmann says "Squamous epithelial cancers occur, which sometimes follow epidermoid transformation of the mucosa, e.g., as a result of concretions. In one such case in Basle the renal pelvis contained a large branching stone (oxalate nucleus with calcium salt mantle) weighing 93.1 gm."

The case reported by Kischensky<sup>6</sup> resembles my case in many respects, especially in the complete replacement of the entire kidney by squamous-cell carcinoma, it also extended into the liver and diaphragm and produced metastases in the regional lymph glands and in the right knee. There was not only squamous-cell cancer tissue, but also areas of transitional and cylindric epithelial growth, and papillomatous formations. In addition to the hornification there was considerable

4 Ewing, James. *Neoplastic Diseases, a Textbook on Tumors*, Ed 1, Philadelphia, W. B. Saunders Company, 1919, pp 743-744

5 Kaufmann. *Spezielle path Anat*, Ed 6, 2 877

6 Kischensky. *Ziegler's Beitr* 30 348, 1901

calcification. However, in this case no concretion was present. He gives a full discussion of the literature on tumors and metaplasia of the renal pelvis to that date.

While squamous-cell cancers of the kidney are rare, as a matter of fact, any type of epithelial tumor seldom arises in the pelvis of the kidney, for in 1921 Miller and Herbst<sup>7</sup> in reporting a case of papillary tumor of the pelvis mentioned only fifty-three others as previously reported. Metastases were observed in fifteen of these cases. Kretschmer,<sup>8</sup> in 1917, reviewed the literature on "Primary Non-papillary Carcinoma of the Renal Pelvis," of which he found forty-three cases, including one of his own. In eleven cases there were found, associated with the tumor, renal stones. Necropsies were secured in but nineteen cases, with metastases found most frequently in the liver (eight cases), and in five cases there were osseous metastases. He makes no particular reference to the question of hornification, and from his abstracts of the case reports it is not possible to determine this matter exactly, since the terms pavement epithelioma and epidermoidal cancer are used vaguely. Apparently only about five cases were definitely keratinizing squamous carcinomas, and in three of these renal stones were found. The cases described by Kaufmann and Ewing were not included in Kretschmer's summary. In all, I have found eleven cases of squamous-cell carcinoma of the renal pelvis sufficiently thoroughly reported to be unquestionable. In these the presence of calculi is mentioned in six.

A case reported by Primrose<sup>9</sup> is particularly interesting since it arose in the pelvis of a horseshoe kidney with calculous pyonephrosis. Unfortunately, necropsy was not obtained and only the observations made at operation are recorded.

Recently Scholl<sup>10</sup> has reported six cases of squamous-cell carcinoma of the urinary bladder, in only one of which did stone occur. In reviewing the literature on the topic he discusses also cases of squamous-cell carcinoma of the renal pelvis. He states that in 195 tumors of the kidney observed at the Mayo Clinic there was only one squamous-cell carcinoma of the pelvis of the kidney, but he does not mention whether there was or was not a stone present. This is presumably the case recorded, but not fully described, by Wilson.<sup>11</sup>

7 Miller, E. M., and Herbst, R. H. Papillary Epithelioma of the Kidney Pelvis. *J. A. M. A.* **76** 918 (April 2) 1921.

8 Kretschmer, H. L. *J. Urology* **1** 405 (Aug.) 1917.

9 Primrose, Alexander. Squamous-Cell Carcinoma of the Kidney, *J. A. M. A.* **75** 12 (July 3) 1920.

10 Scholl, A. I. Jr. Squamous-Cell Carcinoma of the Urinary Bladder, *Arch. Surg.* **3** 336 (Sept.) 1921.

11 Wilson, L. B. Collected Papers of the Mayo Clinic 1912 p. 303.

Scholl also makes the following statement

Leber reports the case of an infant of 4 months in whom the epithelial lining of the pelvis of the kidney was composed of many layers of cells showing cornification, a similar condition was found in the infant's eye. This case suggests a congenital origin. Lecne holds that the process in these cases is due, not to chronic inflammation, but to developmental changes in the genito-urinary tract. Wilson suggests that epidermoid growths of the pelvis of the kidney may be due to inclusions of ectodermal cells carried from the rectum to the kidney by way of the cloacal wall.

The last suggestion is, of course, purely hypothetical. The frequent existence of metaplastic changes in the urinary tract from chronic irritation and the fact that chronic irritation usually precedes squamous carcinoma in the urinary tract provides adequate explanation for such cases as have been observed.

As to the frequency of squamous-cell carcinoma in the urinary bladder, Scholl quotes the statement of Geraghty that in 180 epithelial tumors of the bladder at Johns Hopkins Hospital there was but one of this type. At the Mayo Clinic, however, there were found in 333 neoplasms of the bladder the six cases of squamous-cell epithelioma which Scholl describes. Among 113 bladder tumors studied by Buerger<sup>12</sup> there were five squamous carcinomas.

In their review of the comparative pathology of renal tumors Slye, Holmes and Wells<sup>13</sup> mention only the following cases in which squamous epithelial growths have been observed in the kidneys of lower animals. "Baird<sup>14</sup> has reported a case of keratinizing epithelioma in the kidney of a fowl, and Borrel and Masson<sup>15</sup> have also described a renal tumor in a fowl which showed both cylindrical and squamous elements."

#### SIGNIFICANCE OF METAPLASIA

The occurrence of metaplasia in the urinary tract has been described especially often, presumably because the transitional epithelium has to undergo less alteration to produce squamous epithelium than does the columnar epithelium of the bronchi, uterus and the gallbladder, where metaplasia has been occasionally observed. Richey<sup>16</sup> has recently discussed the topic of metaplasia in the renal pelvis in some detail, and makes the following statement:

That leukoplakia may be the predecessor of carcinoma is indubitable. Osler states that 20 per cent of leukoplakia of the tongue becomes carcinomatous,

<sup>12</sup> Buerger, L. *Surg, Gynec & Obst* **21** 179 (Aug) 1915

<sup>13</sup> Slye, Holmes and Wells. *J. Cancer Res*, to be published

<sup>14</sup> Baird, A. T. *J. Cancer Res* **2** 103 (Jan) 1917

<sup>15</sup> Borrel and Masson. *Bull. de l'ass. franç. p. l'étude du cancer*, Paris,

**4** 172, 1911

<sup>16</sup> Richey, DeW. G. *J. Lab. & Clin. Med* **5** 635 (July) 1920

while Albarran, Barker, Ewing and others indicate that leukoplakia in any organ should be watched carefully for malignancy, often being, in the absence of early carcinoma, very suspicious of precancerous changes. Morris collected twenty-seven cases of tumors originating in the kidney pelvis, of which ten were malignant, while recently Kretschmer was able to gather forty-three instances of nonpapillary carcinoma of the renal pelvis, including twenty-one of apparent transitional or squamous type. The former author states that the most frequent form of carcinoma is transitional or squamous-cell, pointing out that long-standing irritation may lead to the transformation of the renal epithelium to an epidermic character, with a resultant leukoplakia which may be the starting point of squamous-cell cancer.

The formation of metaplastic squamous epithelium brings forward two puzzling topics, one chemical, the other embryologic. The chemical peculiarity is that squamous epithelium is characterized by the formation of keratin, which is a definite chemical compound, formed normally, as far as is known, only by cells of ectodermal origin, including the neurokeratin of the central nervous system. When cells of endodermal origin, such as those lining the gallbladder, or those of mesodermal origin, such as those lining the renal pelvis or the uterus, take on the function of forming this peculiar, insoluble, sulphur-rich, indigestible protective chemical, keratin, they have assumed a chemical function which seems to be far removed from their normal capacity. Hence we must conclude that metaplasia involves not only a morphologic but a chemical transformation in the cells.

For tumor pathology another problem arises. When cells assume the proliferative activity that is characteristic of malignancy, they usually lose their more recently acquired functions and retain chiefly the simple vegetative function of proliferation. But when a transitional or columnar epithelial surface becomes squamous through metaplasia, and the same protracted irritation that produced the metaplasia continues until cancer results, we find that the newly acquired property of forming keratin has become fixed and the cancer is a keratinizing, squamous-cell carcinoma. One would expect the epithelium to approach its original, simpler embryonal character, rather than exhibit and retain so profound and recently acquired an alteration as the production of keratin.

#### SUMMARY

The formation of keratinizing squamous-cell carcinoma in the renal pelvis is a rare occurrence. In the case reported, which is of this sort, the metaplasia of the transitional epithelium to the squamous form was apparently the result of chronic irritation from renal concretions.

# SCOLIOSIS ACCOMPANYING CHRONIC INFECTED OPEN PNEUMOTHORAX ITS CAUSATION AND CORRECTION \*

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Long-continued suppuration of large cavities in open pneumothorax is followed by a deviation of the spine to the healthy side. During the last two years, I have had an unusual opportunity to study this type of case.<sup>1</sup> As a result of these observations, I believe it has been demonstrated that the cause of the scoliosis in these cases is pressure, due to the ribs on the diseased side, proof of which is afforded by the effect of extensive thoracotomy in correcting the deformity.

When the lung is firmly held in a collapsed state by the dense enveloping membrane, which develops in long standing cases of large empyema cavities, nature attempts to obliterate the dead space by approximating the chest wall to the fixed lung. The anterior extremities of the ribs fall, making their horizontal direction more vertical, the intercostal spaces become obliterated, and in very long standing cases, such as the case described herewith, the ribs overlap one another. The shoulder on the affected side drops from 2 to 4 cm, or more, and the middorsal and the lower dorsal spine are pushed over to the unaffected side. In this way a well marked scoliosis, with its concavity toward the affected side of the chest, is produced. The deviation of the spinous processes from the midline may be 3 cm, or more.

In performing decortication, or pneumolysis, in a series of long-standing cases, I have found it necessary to employ, in several cases, a very extensive form of thoracotomy, in order to obtain an adequate exposure of the thorax. As a concomitant of the favorable results of this operation, it has been noted that the scoliosis, which was present in these cases prior to operation, is either entirely corrected or much improved.

If a simple intercostal thoracotomy is performed, normal alignment of the spine is dependent on return of the affected half of the chest to full function. This, at best, must be slow, and it is difficult to imagine its possibility in view of the extreme thickness (1 to 2 cm, or more) of the parietal pleura, and the intercostal fibrosis present in all the more chronic cases.

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\* Read before the fourth annual meeting of the American Association for Thoracic Surgery, Boston, June 6, 1921.

1 Gurd, F B. *Canad M A J* 2 408 (June) 1921.

When, on the other hand, a portion of the lower part of the chest wall is removed, and the upper ribs are divided, there is evident at once a marked change in the shape of the chest. The spine, free from the pressure of the ribs, straightens, and the shoulder returns to its proper position. Both the anteroposterior and the transverse diameters of the diseased half of the chest remain less than those of the healthy side, but the disfiguring deformity is overcome.

In performing this operation, the incision follows the line of the ninth rib from the midline or anterior axillary line, backward to the

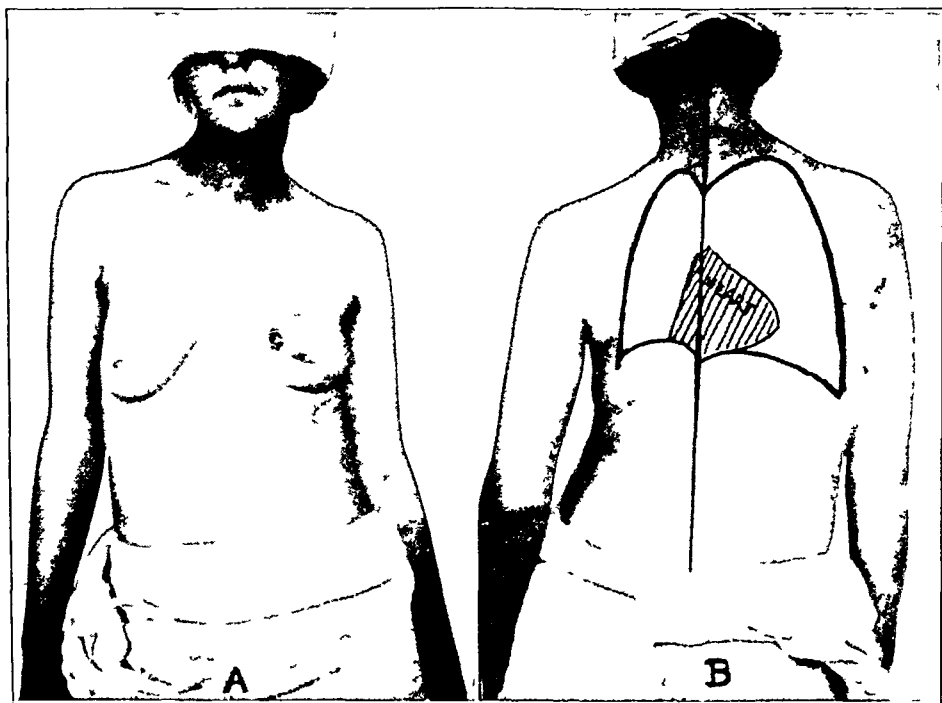


Fig 1—*A*, marked deformity and discharging sinus through the left breast in patient B C, *B*, diagrammatic drawing on photograph, showing marked reduction in size of left half of chest, together with lateral curvature of the spine

angle of the scapula, where it curves upward to about the level of the spine of the scapula and ends midway between the scapula and the spinous processes. From 10 to 15 cm of the eighth and ninth, and occasionally of the tenth rib, are removed, together with the intervening intercostal tissues, and the underlying thickened parietal pleura. The removal of this portion of the wall permits manual, and, to a limited extent, visual exploration of the cavity, and provides for the introduction of tubes for the subsequent use of discontinuous irrigation with surgical solution of chlorinated soda (Dakin's solution). As a general rule, further operative interference should not be undertaken at the primary operation.



Fig 2—Roentgenogram (B C), taken before operation, showing marked curvature of the spine and displacement of the heart to the right



Fig 3—Roentgenogram taken one week after operation showing partial correction of deformity, the clear area on the left side of the chest is the site of removal of thickened parietal pleura

Following this partial thoracotomy, discontinuous irrigation of the cavity should be carried out for two or three weeks, then the second stage of the operation should be undertaken. At the second operation, 5 or 7 cm of the seventh rib is excised, and the sixth, fifth, fourth, and, occasionally, the third, ribs are sectioned. I have not found it necessary or desirable to cut the first two ribs, although that would probably correct more completely the lateral curvature. Such an exposure permits satisfactory intrathoracic operation in the most densely walled chests, and is followed by straightening of the spine.



Fig 4—Roentgenogram (B C), taken one month after operation, showing increase in the size of the left half of the chest, as well as almost complete correction of the deformity.

I have usually employed paravertebral procain anesthesia, assisted from time to time during the operation by light chloroform anesthesia.

The case reported herewith exemplifies the usefulness of decortication in obliterating the open pneumothorax, arresting the suppuration, and correcting the scoliosis.

#### REPORT OF CASE

*History*—B C, woman, aged 23 was admitted to the Montreal General Hospital, Sept 27, 1920. Since May, 1916 she had had a left sided empyema which upon three occasions had ruptured spontaneously. Two sinuses in the lower part of the chest were healed at the time of admission but a moderate purulent discharge poured from an opening through the left breast situated above and toward the midline from the nipple. She had lost 55 pounds (25 kg) and was very emaciated and weak although able to walk about.



*Examination*—The temperature varied from normal to 100.6 F. The pulse rate was about 100 per minute. Blood examination revealed white blood cells, 16,000, red blood cells, 3,000,000, hemoglobin, 80 per cent. She weighed 104 pounds (47 kg).

The heart was displaced completely to the right side of the chest, the apex beat being palpable below the right nipple. Physical and roentgenologic examination indicated a complete cavity of the left chest.



Fig 5—Roentgenogram (B C), taken one month after thoracotomy and pulmonary decortication, showing clearly the tendency of the ribs on the affected side to overlap one another following section.

A marked deformity was present. The left side of the chest was flattened both in front and behind, the axilla was depressed, the shoulder drooped, and there was a marked lateral deviation of the spine, with convexity to the right. The right side of the chest appeared fuller than normal, and respiratory movements were absent on the left side. The spinous processes deviated to the right, between 5 and 6 cm from the midline.

*Operation*—September 30, an incision, 15 cm long, was made over the ninth rib in the axillary line. The ribs overlapped one another by one-third of their width, 9 cm of the eighth, ninth, and tenth ribs were resected. The parietal pleura was extremely dense and hard, and was approximately 2 cm thick. The cavity, which contained about 40 cc of foul, thick pus, was freely exposed. There was no lung in the left side of the chest, and no respiratory or cardiac movements could be felt. Owing to the marked deformity of the chest, the whole left half of the thorax was small. A few adhesions crossing the cavity were broken down, and the surface cleaned with gauze. Two Carrel tubes were sutured in place, and the wound closed.

*Course*—For two weeks following operation, discontinuous irrigation with Dakin's solution was carried out four times a day. During the irrigations, the patient was placed in such a position that as large an amount of the cavity was exposed to the solution as possible. For ten days, the discharge was foul. It then improved rapidly, and by the time of the second operation it was free from odor, although there was a moderate amount of purulent discharge on the dressings.

*Second Operation*—Under intratracheal anesthesia, fifteen days after the preliminary operation, the incision made at the last operation was opened, and continued upward between the spinous processes and the scapula as far as the upper angle of the scapula. The scapular muscles and the remainder of the latissimus dorsi were cut transversely. Four ribs were sectioned upward from the medial border of the previous operation, 7 cm of the seventh rib was excised, and shorter portions of the fifth and sixth ribs. The thickened pleura was partly excised, to obtain satisfactory exposure, a procedure made necessary by intercostal fibrous tissue and thickened parietal pleura. With difficulty, the covering over the lungs was removed completely over the lower two thirds, above this point it was separated from the lung surface and incised. The covering over the pericardium, and over the greater portion of the diaphragm was also removed. Considerable bubbling occurred from the surface of the lung over parts which had been torn during decortication. Although the patient could not be induced to cough, it was obvious that the lung was still expansile. The wound was closed by catgut sutures for the muscle, and silk-worm-gut for the skin. Two long paraffin gauze bismuth-iodoform-petrolatum-paste drains were inserted in the apex of the cavity and brought out through the lower anterior portion of the wound.

*Result*—The patient stood the operation well. For forty-eight hours she was moderately weak, although her pulse did not rise above 100 per minute and the temperature remained practically normal. The drains, behind which was found about 20 cc of bloody serum, were removed forty-eight hours after operation. The wound was allowed to close, and forty-eight hours later a director was passed into the chest. Only a few drops of clear serum was evacuated. At no time, subsequently, was there the slightest discharge from the wound.

The fourth day following operation the following note was made. The patient feels strong and is suffering but little discomfort. The deformity of the chest has been corrected to a considerable degree. Scoliosis is not more than 2.5 cm from the midline.

The patient was discharged from the hospital Nov. 4, 1920. The wound was then soundly healed. Her general appearance was much improved and she was

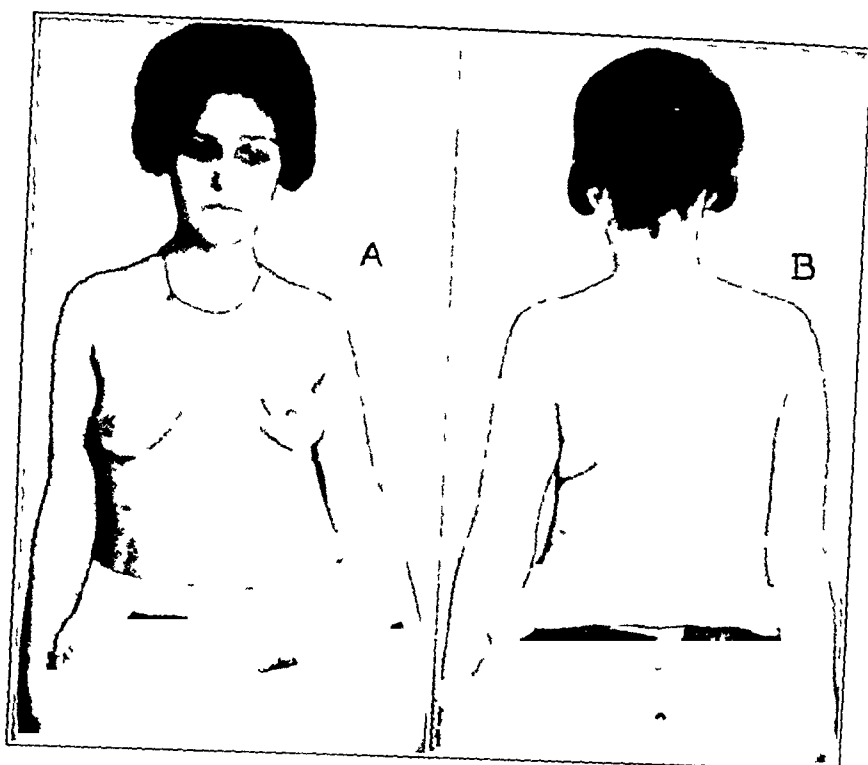


Fig 6—*A*, anterior view of patient six weeks after operation, *B*, posterior view six weeks after operation

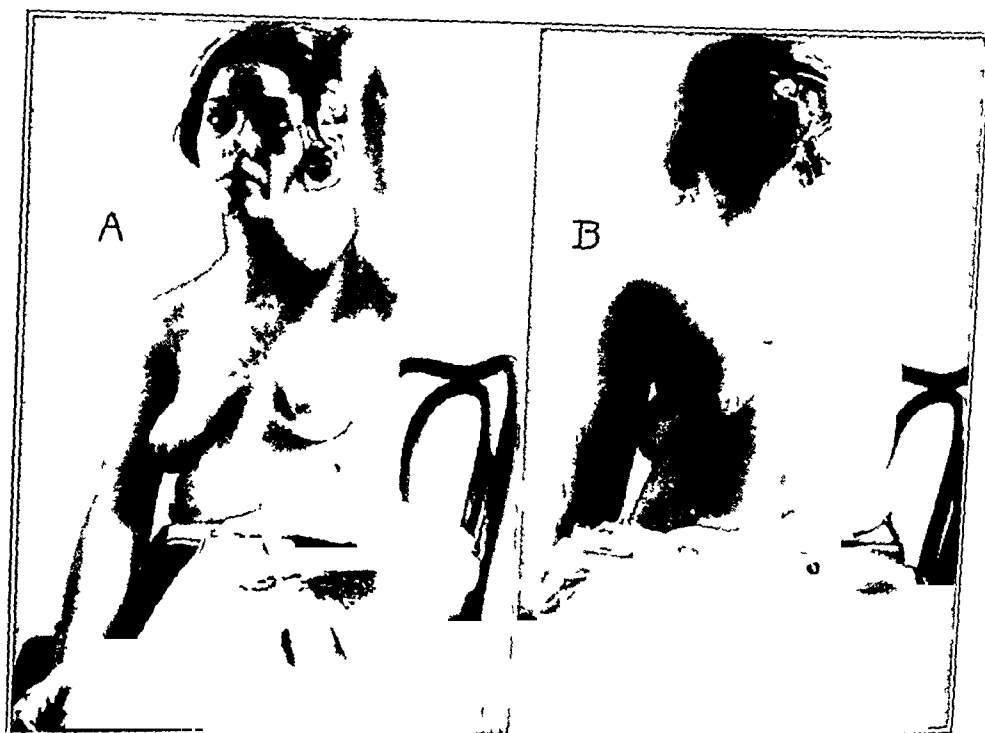


Fig 7—*A*, patient, six weeks after operation, showing lack of interference with function of the arm, *B*, posterolateral view showing operation wound

able to get about without undue fatigue. She weighed 107 pounds (48.5 kg) and breath sounds of a blowing character were heard through the chest, except toward the midline posteriorly.

The left shoulder was practically on a level with the right. The deviation of the spinous processes to the right was less than 2 cm.

Since leaving the hospital, the patient has been repeatedly examined. There has been a continuous improvement in her general health, although late in January she had an attack of diphtheria. There is now, May 30, 1921, moderately good expansion of the left side of the chest, and, although it is obvious on examination that the left half of the chest is smaller than the right, when she is wearing her clothing the deformity is not noticeable. She is at present engaged at work as a ward maid in the hospital. She weighs 129 pounds (58.4 kg).

#### COMMENT

Although in no other case have I encountered such a marked degree of scoliosis, in all cases in which chronic infected open pneumothorax has persisted for six months or longer, there is marked lateral curvature of the spine. Ten cases of this kind have been observed in which correction of the deformity has followed extensive thoracotomy. In one patient, who is still under observation, decortication of the lung did not prove successful in inducing obliteration of the cavity, and an extensive resection of the chest wall was performed. Resection of the posterior segments of all the ribs, from the second to the tenth, inclusive, was performed. This interference has been followed not only by correction of the curvature of the spine toward the healthy side, but also by a moderate scoliosis projecting toward the diseased side, as demonstrated by roentgenograms. Apparently, in this case, the complete removal of pressure of the ribs upon the spine has resulted in deviation of the spine to the unsupported side.

#### CONCLUSION

Chronic infected open pneumothorax if long continued is followed by scoliosis. Curvature of the spine is toward the healthy side of the chest, and is consequent upon pressure exerted upon the spine by the contracting ribs on the diseased side.

Correction of the deformity may be accomplished by means of an extensive thoracotomy with removal and division of several ribs.

# THE FUNCTION OF THE GALLBLADDER IN BILIARY FLOW

CONRAD JACOBSON, M D

SI ATT I F

AND

CARL GYDESEN

MINN I A P O L I S

Bile, a product of liver action, has a dual nature (1) a secretion, a digestive fluid, produced in largest quantities and required most abundantly during the periods of digestive activity, (2) an excretion formed from the disintegration of hemoglobin in the destruction of red blood corpuscles, a continuous process in the body economy. The physiologically periodic outflow into the small intestine of a fluid continuously produced is maintained supposedly by a reflex mechanism between the alimentary canal and the gallbladder, the latter a diverticulum so to speak, of the extrahepatic passages in which the bile is supposedly stored between the intervals of gastric activity.

In the gallbladder certain changes occur in the composition of this storage bile. There is a loss of water by concentration, a change in color and an increase in the specific gravity owing to the addition of certain mucins and nucleo-albumins. Whether these changes are essential to the body welfare or concerned in the expulsion of bile from the gallbladder, it is difficult to say. As a reservoir for bile, the gallbladder cannot be considered mechanically adapted not only because of its relatively small capacity as compared to the large amount of bile secreted but also because of its lack of inherent propulsive power. Certain features of a physiologic character, however, indicate that the gallbladder and passages exert an important function as regulators of biliary flow, and it is with this feature that this paper is primarily concerned.

## ANATOMIC CONSIDERATIONS

According to Hendrickson<sup>1</sup> and Helly,<sup>2</sup> the gallbladder has a moderate amount of smooth muscle fibers, not arranged with any uniformity in definite muscle layers and coats but rather as a smooth muscle complex with fibers running in three directions, transversely, longitudinally, and obliquely, the greatest number of them run transversely, that

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1 Hendrickson, W F. A Study of the Musculature of the Entire Extrahepatic Biliary System Including That of the Duodenal Part of the Common Bile Duct and Sphincter, *Bull Johns Hopkins Hosp* 9 221-232, 1898

2 Helly. Die Schliessmuskulatur an den Mundungen der Gallen und der Pankreasgange, *Arch f mikr Anat* 54 614, 1899

is, perpendicular y to the long axis of the gallbladder. There is a small amount of connective tissue between these muscle fibers, and, as a rule, the walls are fairly well covered with this muscle complex. As a contractile mechanism, however, it forms quite a contrast to the more definite muscular viscera, such as the urinary bladder, stomach, intestine and uterus.

The wall of the cystic duct has also a plexiform arrangement of smooth muscle fibers, extending in the three above mentioned directions, the transverse fibers predominating, with only small amounts of longitudinal and oblique fibers. That portion nearest the neck of the gallbladder has a considerable amount of muscle tissue, but this gradually diminishes as the common duct is approached, so that at the junction of the cystic and common ducts it is of very small amount or entirely absent. Inside the cystic duct, there is a peculiar configuration of the walls described by Heister<sup>3</sup> in 1732, and since named after him "Heister's valve," a "spiral valve" arrangement whose function has been, supposedly, to permit the passage of bile for storage purposes into the gallbladder and to allow its release to meet the demands of digestion. Hartmann<sup>4</sup> made a careful macroscopic examination of this valve under water, and Faure<sup>5</sup> studied it grossly by making metal models. These men noted the "bassinet" shape of the cystic duct and the angle it made with the neck of the gallbladder. They concluded that it did not have a spiral canal but that the lumen was free, with minor constrictions of the walls, producing a series of valvelike projections not of constant configuration. These leaflets or valves were most numerous in the upper portion of the duct. The upper two were the largest and extended about three-fourths the distance around the lumen of the cystic duct, so that it would be impossible to catheterize the duct without breaking the leaflets, there might be resistance to the passage of solid matter but hardly, in normal conditions, to liquids. Terrier and Dally<sup>6</sup> supported this description, especially regarding the presence of the upper two large leaflets, but found a larger number of smaller valves in the lower part of the duct. In the specimens they examined, the number of leaflets ranged from four to twenty. Hendrickson<sup>1</sup> has carefully studied the microscopic anatomy of the cystic duct valves. According to him, the transverse muscle fibers of the wall

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3 Heister. *Compendium anatomicum totam rem anatomicam brevissime complectens*, Ed. 4, Nuremberg 1 89, 2 65, 1732.

4 Hartmann. *Quelques points de l'anatomie et de la chirurgie des voies biliaires*, Bull. Soc. anat. de Par. 66 480, 1891.

5 Faure, J. L. *Quelques points de l'anatomie du canal cystique*, Bull. Soc. anat. de Par. 66 511, 1891.

6 Terrier and Dally. *Du catheterisme des voies biliaires*, Rev. de chir. 12 136, 1892.

of the cystic duct also run around the valves or leaflets in a circular direction. It is as if the wall of the duct was invaginated at the level of the valve and the circular muscle fibers carried out into the fold thus produced. Most of the longitudinal muscle fibers continue down the wall of the duct without entering the valve but some of these bend at right angles and enter the valve at the proper level. The oblique fibers did not enter the valve and formed no part of the musculature of that structure. It is thus seen that the transverse muscle fibers are the predominant ones in the valves of Heister. These valves near the common duct are very small indeed and have only a few muscle fibers, if any.

The hepatic and common ducts are almost alike in microscopic anatomy. There is a very small amount of muscle tissue, with a large amount of connective tissue between them. These muscle strands are mainly of the transverse variety.

The duodenal portion of the common duct has, during recent years, received considerable attention as the important feature of the mechanism of biliary control. The presence of some sort of sphincter about the orifice of the common duct was suggested by Glisson,<sup>7</sup> as early as 1681. Ruggero Oddi,<sup>8</sup> however, in 1887 was the first to describe a sphincter arrangement, which to this day is known as the sphincter of Oddi. After careful study of maceration specimens and microscopic sections of the duodenal end of the common duct, he described a definite and independent ring of muscle tissue about the mouth of the duct, entirely separate from the muscle of the intestinal wall through which it plunged, some of the delicate muscle fibers of which were reflected upon the sphincter's external surface. This sphincter, according to Oddi, could be put into spasm by irritation, mechanical or chemical, from the duodenal side. It was able to withstand an interductal pressure of 675 mm of water, sphincteric action caused an intermittent flow of bile into the duodenum and seemed to maintain a definite pressure in the hepatic duct system. Oddi also observed the dilatation of the extra-hepatic ducts in dogs following the removal of the gallbladder. Oddi made no attempt to demonstrate this sphincter muscle in man. Hendrickson,<sup>1</sup> in 1898, and Helly,<sup>2</sup> in 1899, confirmed the microscopic anatomy, in man, of the sphincter of Oddi as a special and separate entity from the intestinal musculature through which the common duct enters at the ampulla of Vater. Archibald,<sup>9</sup> in 1912 and 1913, verified the

7 Glisson, quoted by Hendrickson, W. F. Footnote 1

8 Oddi, Ruggero. Di una speciale disposizione a sfintere allo sbocco del coledoco, *Ann d Univ libera di Perugia Fac di med e chir* 2 249, 1886

9 Archibald. A New Factor in the Causation of Pancreatitis, *Tr Inter Cong Med, Surg Sect Part II*, pp 7-21, 1913, The Experimental Production of Pancreatitis in Animals as the Result of the Resistance of the Common Duct Sphincter, *Surg, Gynec & Obst* 28 529 (June) 1919

action of the sphincter in maintaining an interductal pressure and showed that incision of the sphincter causes a reduction of the high interductal pressure from 650 mm to 70 mm of water, which low level persists for many weeks, if not permanently. He observed the production of acute pancreatitis by introduction of bile and other substances into the pancreas under pressures higher than the normal interductal pressures and suggested incision of the sphincter of Oddi as one of the steps in the surgical treatment of that condition. Judd and Mann,<sup>10</sup> in 1917, by extirpation of the gallbladder in dogs, demonstrated the great dilatation of the extrahepatic ducts after cholecystectomy. Following the operation, the sphincter is evidently contracted, attempting to maintain the normal interductal pressure. The ducts as a consequence dilate, and the sphincter, under the continued pressure, becomes paralyzed, with ultimate reduction of the interductal pressure.

#### NERVOUS CONTROL

Heidenhain,<sup>11</sup> 1861, was the first to make accurate investigation of the nervous control of biliary flow. By stimulating the spinal cord in the cervical region, he obtained an increased flow of bile followed shortly afterward by decreased biliary output. Contraction of the gallbladder, with expression of its bile content, accounted for the increased flow, the increased pressure in the biliary passages, produced by the contraction, acted directly on the secretory cells and caused a decreased secretion.

Doyon,<sup>12</sup> 1893, by using the balloon and recorder method, showed graphically that the gallbladder underwent spontaneous contractions of a rhythmic character. By stimulation of the peripheral ends of the splanchnic nerves, he obtained a slow contraction of the gallbladder and the biliary passages while an inhibiting effect resulted from stimulation of the central end. Inhibition of gallbladder tone followed stimulation of the central end of the vagus nerve. He believed that the motor fibers reached the gallbladder by way of the splanchnic nerves and that the vagus nerve carried only afferent fibers from the gallbladder.

Courtada and Guyon,<sup>13</sup> 1904, evidently accepted Doyon's conclusions regarding the motor mechanism of the splanchnic nerves and limited their efforts mainly to stimulating the peripheral end of the vagus nerve, from which they obtained definite motor responses. They

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10 Judd and Mann. The Effect of the Removal of the Gallbladder. An Experimental Study, *Surg., Gynec. & Obst.* **24** 437 (April) 1917.

11 Heidenhain. Studien des physiologischen Instituts zu Breslau, Leipzig, Breitkopf and Hartel **2** 82, 1863.

12 Doyon, M. Contribution a l'etude de la contractilite des voies biliaires, application de la methode graphique a cette etude. *Arch. de physiol. norm. et path.* **5** 678-710, 1893.

13 Courtada and Guyon. Action motrice du pneumogastrique sur le vesicule biliaire, *Compt. rend. Soc. de biol.* **56** 313-874 1904.



asserted that they had traced these motor fibers into the gastric branches of the vagus nerve along the lesser curvature of the stomach and indicated that the motor control of intestine, stomach and gall-bladder is contained in one and the same nerve, the vagus. Freeze,<sup>14</sup> 1905, also obtained rapid rhythmic spontaneous contractions of the gall-bladder. By stimulation of the splanchnics, he obtained a variety of results leading to the conclusion that these nerves contained both motor and inhibitory fibers from the gallbladder but that the motor fibers predominated. Bainbridge and Dale,<sup>15</sup> 1905, also used the balloon and recorder method, with modifications, and endeavored to remove a number of extraneous factors which undoubtedly influenced Doyon's and Freeze's conclusions regarding the motor effect of the splanchnic nerves. They seem to have proved in no uncertain manner that 1. There are spontaneous rhythmic contractions of the gallbladder. 2. Stimulation of the splanchnics always results in relaxation of the gall-bladder. 3. The vagus contains the motor innervation of the gallbladder.

#### CHEMICAL HORMONE REFLEX CONTROL

Claude Bernard,<sup>16</sup> 1856, was the first to observe the stimulating effect of acids upon the duodenal orifice of the common duct, a sudden gush of bile into the intestines resulting from such an application. Heidenhain,<sup>17</sup> 1861, attributed the sudden gush of bile occurring at a certain interval after a meal to the stimulating action of the acid and chyme upon the biliary papilla, causing a reflex stimulation of the gall-bladder. Rutherford,<sup>17</sup> 1880, observed that the introduction of nitro-hydrochloric acid into the duodenum stimulated liver secretion. Wertheimer<sup>18</sup> also observed, in 1890, increased biliary outflow in case acid is introduced into either the duodenum or upper jejunum. Baylis and Starling,<sup>19</sup> 1902, using purified specimens of secretin (removal of depressor substance) intravenously, obtained an increased secretion of bile quite similar to the pancreatic outflow. Fleig,<sup>20</sup> 1904, noted that

14 Freeze, J. A. The Force of Contraction of the Gallbladder and the Course of Its Motor and Inhibitory Nerve Fibres, *Bull. Johns Hopkins Hosp.* **16** 235, 1905.

15 Bainbridge and Dale. The Contractile Mechanism of the Gallbladder and Its Extrinsic Nervous Control, *J. Physiol.* **33** 138, 1905-1906.

16 Bernard, Claude. *Leçons de physiologie expérimentale*, 1856, p. 429.

17 Rutherford, Vignol and Doods. An Abstract of an Experimental Research on the Physiological Actions of Drugs on the Secretion of Bile, *Tr. Roy. Soc. Edin.* **29** 133, 1880.

18 Wertheimer. De l'action et du chloral sur la sécrétion biliaire, *Compt. rend. Soc. de biol.* **55** 286, 1903.

19 Baylis and Starling. The Mechanism of Pancreatic Secretion, *J. Physiol.* **38** 21, 1902.

20 Fleig. Du mode d'action des excitants chimiques des glandes digestives. *Arch. internat. de physiologie*, 1904, p. 286.

the intravenous injection of blood from an isolated loop of duodenum-jejunum into which 0.5 per cent hydrochloric acid had been introduced caused a similar increase in bile flow. On the other hand, Bainbridge and Dale<sup>15</sup> 1905, found no reflex effect on gallbladder contractions when 0.4 per cent hydrochloric acid was injected into the duodenum or applied directly to the papilla or even when the papilla was electrically stimulated.

Prevost and Binet,<sup>21</sup> 1888, found great acceleration of biliary secretion on introduction of peptone into the stomach. Doyon,<sup>22</sup> 1897, on the other hand, concluded that peptone introduced into the stomach had an inhibiting effect upon the secretion of bile but caused an expulsion of bile from the gallbladder through vigorous contractions. Ascher and Barbera,<sup>23</sup> 1904, injected peptone intravenously into dogs with permanent biliary fistula and observed increased flow of bile. Fleig<sup>20</sup> noted also the increase in biliary flow on introduction of peptone into the intestine, and since the increase was more pronounced after ligation of the cystic duct, he concluded that it was essentially secretory in character, produced by reflex stimulation of the liver cells. A moderate stimulating effect of meat extract upon the biliary flow in animals with Pawlow stomachs was noted by Bruno, but quite opposite findings are reported by Klodnizka.<sup>24</sup> Fleig<sup>20</sup> found no acceleration of bile flow on injection into the rectum or into the blood stream of meat extracts or meat extract solutions of gastric or duodenal mucosa or on intravenous injection of blood from duodenal loops that contained in their lumen the above named solutions. More recently, Rost,<sup>25</sup> 1913, working with animals with duodenal and biliary fistulas, asserts that he has found an immediate discharge of bile as a result of the contractions of the gallbladder and a relaxation of the sphincter of Oddi when peptone was injected into the open duodenal fistula.

Nasse and Ritter<sup>26</sup> showed that a meat diet called forth a larger biliary outflow than a carbohydrate diet and that fat, in small quanti-

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21 Prevost, J. E., and Binet, P. *Recherches experimentales relatives a l'action des medicaments sur la secretion biliaire et a leur elimination par cette secretion*, *Rev. med. de la Suisse Rom.* **8** 249, 313, 368, 1888.

22 Doyon, M., and Dufourt, E. *Contribution a l'etude de la secretion biliaire*, *Arch. de physiol. norm. et path.* **8** 587, 1897.

23 Ascher and Barbera, quoted by Fleig. *Arch. internat. de physiol.*, 1904, p. 286.

24 Bruno and Klodnizka, quoted from Babkin. *Die aussere Sekretion der Verdauungsdrusen*.

25 Rost, F. *Die funktionelle Bedeutung der Gallenblase. Experimentelle und anatomische Untersuchungen nach Cholecystektomie*, *Mitt. a. d. Grenzgeb. d. med. u. Chir.* **26** 710, 1913.

26 Nasse and Ritter, quoted from Stadelmann. *Der Icterus*, 1897.

ties, had a stimulating effect upon the bile flow, which was lacking with larger quantities. Bidder and Schmidt<sup>27</sup> found that continued meat diet increased the secretion of bile, while a continued fat diet diminished the secretion to a level found in starvation. The latter conclusion was confirmed by Prevost and Binet<sup>21</sup> in 1888. Rosenberg,<sup>28</sup> 1890, believed that fat possessed a greater stimulating effect upon bile secretion than either a protein or carbohydrate diet, his observations indicated an interval or periodic secretion of bile at the usual time of feeding, the food itself not being a necessary factor. Albertoni and Barbera,<sup>29</sup> 1895, concluded that the greatest secretion occurred on a protein diet, less on a fat diet and very little or insignificant secretion on a carbohydrate diet. On a mixed diet, the ultimate biliary effect depended upon the predominant constituent, the duration of secretion was, however, longest on a fat diet, shorter on a meat diet and very short on a carbohydrate diet. On a mixed diet the duration of secretion also depended upon the amount of fat and protein present. They also observed that while the amount of bile secreted during starvation diminishes to a marked degree, there is never a complete cessation of secretion even up to the time of the death of the animal.

Schiff,<sup>30</sup> 1870, and later Rosenberg,<sup>28</sup> 1890, noted that introduction of bile into the alimentary canal was followed by an augmented flow of bile of increased concentration in contrast to the usual diluted bile produced by the action of ordinary cholagogues. This led him to infer that the bile was absorbed and re-excreted as a whole, thus forming a continuous circulation of bile, as it were, between the intestine and the liver. Socoloff,<sup>31</sup> 1875, was led to believe otherwise, holding that the liver was incapable of resecrting the bile that had once been secreted and absorbed into the blood stream. He believed the augmented secretion was due to the mechanical passage of these absorbed substances from the blood which was overcharged with them. Rosenberg, however, points out that while this would account for the increased secretion, it would hardly account for the increased concentration which is found experimentally.

Okada,<sup>32</sup> 1914, in a well managed, extensive series of feeding experiments on dogs, with permanent biliary fistulas and ligation of the com-

27 Bidder and Schmidt, quoted from Hermanns Handb d Physiol 5 256

28 Rosenberg Ueber die cholagogische Wirkung des Olivenols im Vergleich zu der Wirkung einiger andern Cholagogen Mittel, Arch f Physiol 46 334, 1890

29 Barbera L'eliminazione della bile nel digiuno e dopo differenti generi di alimentazione, Arch ital de biol 23 165 1895

30 Schiff Bericht uber einige Versuchsreihen, Arch f d ges Physiol 11 589-624, 1870

31 Socoloff Ein Beitrag zur Kenntnis der Lebersekretion, Arch f d ges Physiol 11 166, 1875

32 Okada On the Secretion of Bile, J Physiol 49 457-482, 1914-1915

mon duct by feeding by stomach, the more normal way, and by excluding many extraneous factors and extending his observations over longer periods after feedings, confirmed or refuted many of these former diversified conclusions. From his experimental findings he drew these conclusions: 1. There is little difference between the secretory effect of a diet of bread, butter and meat during six or seven hours if these substances are introduced in quantities of similar caloric values. 2. Starvation decreases the secretion of bile and also the stimulating effect of feeding upon the liver. 3. Fat, acid, peptone, meat extract, bile and bile salts, all produce increased secretion of bile. Bile and bile salts produce an augmentation of concentrated bile, the others of a more dilute bile. 4. Cane sugar, water and sodium carbonate have little or no effect upon the secretion of bile. 5. Intravenous injections of secretin and peptone cause increased secretion of a dilute bile. 6. Biliary flow in response to acid stimulation exhibits a course quite similar to that displayed by the pancreatic secretion.

#### LAW OF CONTRARY INNERVATION

In 1917 Meltzer<sup>33</sup> applied the law of contrary innervation to explain the interrelated and coordinated action of relaxation of the sphincter of Oddi and the simultaneous contraction of the gallbladder in the mechanism of biliary control. He had previously noted "that the local application of a 25 per cent solution of magnesium sulphate to the duodenal mucosa had caused a completely local relaxation of the intestinal wall." No such action was noted when the salt was introduced through the stomach. He made the practical suggestion that in some pathologic conditions this coordinated nervous mechanism might be disturbed, as by some spasticity or rigidity of the sphincter. In such cases, the instillation of concentrated magnesium sulphate, through a duodenal tube, might cause a relaxation of the nonfunctioning sphincter, with relief of the distressing symptoms caused by cessation of biliary flow into the duodenum.

Lyon,<sup>34</sup> in a large series of cases and in several articles, claims to have confirmed Meltzer's theory in a practical manner. The instillation of concentrated magnesium sulphate into the duodenum by a duodenal tube, in human subjects, was followed by the evacuation of bile in large quantities, and he has been able to segregate and examine the bile coming from (1) the common duct, (2) the gallbladder, and (3) the liver. He believes that the method is of much moment in the nonsurgical drainage of the gallbladder and biliary passages. He con-

33 Meltzer. The Disturbance of the Law of Contrary Innervation as a Pathological Factor in Diseases of the Bile Ducts and the Gallbladder, *Am J M Sc* **153** 469-477 (April) 1917.

34 Lyon, B. B. V. Diagnosis and Treatment of Diseases of the Gallbladder and Biliary Tract, *J A M A* **73** 980 (Sept 27) 1919.

sideris concentrated magnesium sulphate a "chemical messenger," hormone, which has the ability not only to cause relaxation of the sphincter of the common bile duct but also to cause simultaneously the contraction of the gallbladder and the expulsion of its contents

No definite laboratory demonstration of the law of contrary innervation in the gallbladder mechanism has ever been shown and it is with this feature that the experimental data herewith given have been concerned

#### EXPERIMENTAL DATA

Examination of the duodenum of a dog during the fasting stage reveals a slightly elevated papilla discharging no bile. Inserting a fine dropping glass cannula into the lumen of the common duct through the papilla, one can obtain a sudden gush of a few drops of bile, bile from the common duct and biliary passages, maintained there, no doubt, by the competent sphincter of Oddi. There then follows a drop of bile at long intervals, this bile being the continuous secretion of the liver. During digestion, there is a continuous flow of yellow thin bile into the duodenum. The papilla then is easily stimulated to contraction by rubbing with gauze, flicking with the finger or by chemical irritation. The duct appears suddenly to contract, becomes slightly erect, and the flow of bile ceases for from fifteen to thirty seconds. Relaxation follows and the continuous flow of bile is reestablished. In the fasting stage relaxation of the closed sphincter was readily obtained by mechanical and chemical irritation, being followed by a small momentary expulsion of bile. It is extremely difficult to say whether the papilla alone was stimulated, the reaction always seemed to include the duodenum surrounding the base of the papilla, and if the stimulus was great enough, to involve the whole segment of the duodenum and even to cause a progressive peristalsis.

#### SPHINCTER PRESSURE

With the ampulla exposed through an opening in the duodenum, with a right-angled cannula inserted into the common duct, with the open end toward the ampulla and connected with a pressure bottle filled with water deeply colored with methylene blue as an indicator, the sphincter pressure was determined in a series of dogs. By carefully elevating the pressure bottle, a level is reached at which there is a continuous flow of colored fluid through the papilla. When the pressure bottle is lowered slowly, there is a spurt of bile through the orifice, decreasing in quantity, with every respiratory effort, the respiratory impulse being transmitted through the diaphragm to the intestine as a wave. This continues until a still lower level is reached where no fluid is expelled through the orifice. The lower level represents, undoubtedly, the absolute pressure maintained or supported by the

sphincter of Oddi. The former level seems to represent this sphincter pressure plus the resistance of the valvelike effect produced by the oblique course of the terminal end of the common duct through the duodenal wall. Local application, by a cotton swab or by dropper, was then made to the papilla and neighboring duodenum of (1) 25 per cent magnesium sulphate, (2) 5 per cent peptone solution, (3) 0.4 per cent hydrochloric acid, (4) 0.4 per cent, sodium hydroxide. Measurements of the sphincter pressure both before and after application in each case were made. The reaction appears to be mainly a local one, affecting both the papilla and the duodenum. It is of short duration and normal

TABLE 1—DETERMINATION OF THE PRESSURES AT THE SPHINCTER OF ODDI IN A SERIES OF DOGS

	Pressures in Mm. of Water							
	Animal 1	Animal 2	Animal 3	Animal 4	Animal 5	Animal 6	Animal 7	Animal 8
Normal								
Total pressure	140	270	364	190	170	340	420	244
Sphincter pressure	90	160	100	110	94	140	210	114
Difference	50	110	264	80	76	200	210	130
Magnesium Sulphate								
Sphincter pressure—before	100	156	104	110	100	150	210	108
Sphincter pressure—after	40	62	48	60	42	60	120	38
Difference	60	94	56	50	58	90	90	70
Peptone 5 per cent solution								
Sphincter pressure—before	92	160	102	106	104	146	184	120
Sphincter pressure—after	72	112	70	82	86	96	142	84
Difference	20	48	32	24	18	50	42	36
Acid 0.4 per cent hydrochloric								
Sphincter pressure—before	92	148	110	116	98	152	200	132
Sphincter pressure—after	114-52	30	142-70	70	62	268-78	80	410-72
Difference	40	118	40	46	36	74	120	60
Alkali 0.4 per cent sodium hy droxide								
Sphincter pressure—before	98	144	112	122	104	148	190	126
Sphincter pressure—after	112	150	320-82	128	180-82	122	320 180	673-160
Difference	24	6	30*	6	22*	26	10†	334†

\* Return to normal pressure in five minutes

† Prolonged increase in interductal pressure, no return to normal in twenty minutes

conditions are readily established. The results in eight typical cases, in dogs ranging from 35 to 45 pounds (15.9 to 20.4 kg) in weight, are given in Table 1.

#### EFFECT OF MAGNESIUM SULPHATE ON SPHINCTER PRESSURE

1. The absolute sphincter pressures here determined are somewhat lower than those usually given. Oddi<sup>8</sup> and Archibald<sup>9</sup> found unusually high values, from 650 to 675 mm of water. Herring and Simpson<sup>35</sup> report pressures of from 200 to 300 mm. Mann<sup>36</sup> finds most of them

35. Herring and Simpson. The Pressure of Bile Secretion and the Mechanism of Bile Absorption in Obstruction of the Bile Duct. *Proc. Roy. Soc. London* **79**: 517-532, 1907.

36. Mann, I. C. The Function of the Gallbladder. An Experimental Study. *New Orleans M. & S. J.* **71**: 80 (Aug.) 1918.

ranging between 100 and 150 mm. McWhorter<sup>37</sup> reports the majority between 100 and 200 mm., with some as low as 50 mm. and others as high as 580 mm. of water. Smoothness of anesthesia, peristalsis, transmitted respiratory pressure, pressure from contiguous organs, all have their effect in modifying the results obtained, one gains the impression, however, that if all the extraneous factors could be removed, the absolute pressure maintained by the papillary sphincter of Oddi would be much lower than usually supposed, probably less than 150 mm. of water.

2 Magnesium sulphate does produce a relaxation of the papillary sphincter with reduction of the intraductal pressure. As Meltzer has said, it produces a "completely local relaxation", it involves the sphincter and the surrounding duodenum and with an increase in the amount of the magnesium salt, there is segmental relaxation, leading to advancing peristalsis. The latter is especially well marked when magnesium sulphate in larger amounts (from 5 to 10 cc.) is injected through the wall into the lumen of the bowel. A regular advancing peristalsis of the duodenal tube follows.

3 Local application of magnesium sulphate is followed by a momentary relaxation of the sphincter followed by a spurt of bile from the papillary orifice and a lowered intraductal pressure. Normal pressure is readily established, usually in less than two minutes and most commonly in less than one minute. When larger amounts of the magnesium salt are left in the unopened bowel, the relaxation may be of longer duration and complicated by the characteristic active peristalsis. It is quite impossible from the determinations made to conclude whether there was produced a local complete relaxation. McWhorter does not find the sphincter completely relaxed. Making the determinations as quickly as possible, the lowest intraductal pressure found in the animals under observation was 30 mm. of water. McWhorter has also reported changes in the intraductal pressure, from the application of magnesium sulphate to the duodenal mucosa, of from 50 to 100 mm. of water.

4 Much less relaxation was obtained by application of a 5 per cent peptone solution. Acids, 0.4 per cent, tend to be followed by a contraction, with increased intraductal pressure but with a subsequent decrease in pressure greater than that caused by peptone. As a rule, alkali, 0.4 per cent sodium hydroxid, was followed by a contraction and a long enduring increase in the intraductal pressure, the return to normal being delayed in some instances to twenty minutes. There seems to be a definite shrinking of the mucosa with the stronger acids and alkalis, and this no doubt alters the findings. Acids and alkalis, stronger

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37 McWhorter, G. L. The Surgical Significance of the Common Bile Duct Sphincter, Surg., Gynec. & Obst. **32** 124-129 (Sept. 17) 1921.

than 0.4 per cent would not be encountered in the duodenum normally, and such results would have no special relation to the normal human mechanism.

Attempts were made to show graphically the change in the intraductal pressure in the common duct and in the gallbladder, if any, from the application of magnesium sulphate to the duodenal mucosa and the biliary papilla. The pressure is quite low and it was difficult to get a graphic record of the pressure change. A cannula was inserted into the common duct of an unusually large dog. To the free end was attached a very thin rubber balloon filled with water and in equilibrium with the intraductal pressure. This was introduced into a glass tube or bulb filled with oil and connected to a delicate piston, a lever recording manometer to record on a revolving smoked drum. Any change in the intraductal pressure was accompanied by a movement of the lever. Two different methods were used to determine the gallbladder pressure. In one there was cannula, balloon, water and oil manometer system, like that used for the common duct. In the other method, a balloon of very thin rubber was inserted into the gallbladder, filling it completely. The balloon was filled with thin oil and connected with a recording manometer and smoked drum. In no case was there any evidence of a change in the gallbladder pressure, either in the nature of a relaxation or of a contraction of the gallbladder itself, as a result of the application of the magnesium sulphate to the duodenal mucosa. A definite fall in the intraductal pressure in the common duct was demonstrated. Figure 1 shows a definite lowering of pressure in the common duct and no appreciable change in the gallbladder pressure on the application of 25 per cent magnesium sulphate to the mucosa of the duodenum.

#### GALLBLADDER PRESSURE AND MAGNESIUM SULPHATE

The absence of any definite gallbladder effect due to the application of concentrated magnesium sulphate to the duodenal mucosa and the biliary papilla was further substantiated by the following procedures:

1. A fine water manometer attached to the gallbladder showed neither rise nor fall in pressure on such application of magnesium sulphate to the duodenum, though it was accompanied by a relaxation of the sphincter of Oddi and by a spurt of yellow bile through the papillary orifice.

2. With a fine right angled dropping cannula inserted into and attached to the fundus of the gallbladder, the gallbladder normally empties itself according to the following rate and curve plotted for that particular cannula and gallbladder: first five minutes, 59 drops, second five minutes, 55 drops, third five minutes, 48 drops, fourth five minutes, 38 drops, fifth five minutes, 28 drops, and sixth five minutes, 10 drops.



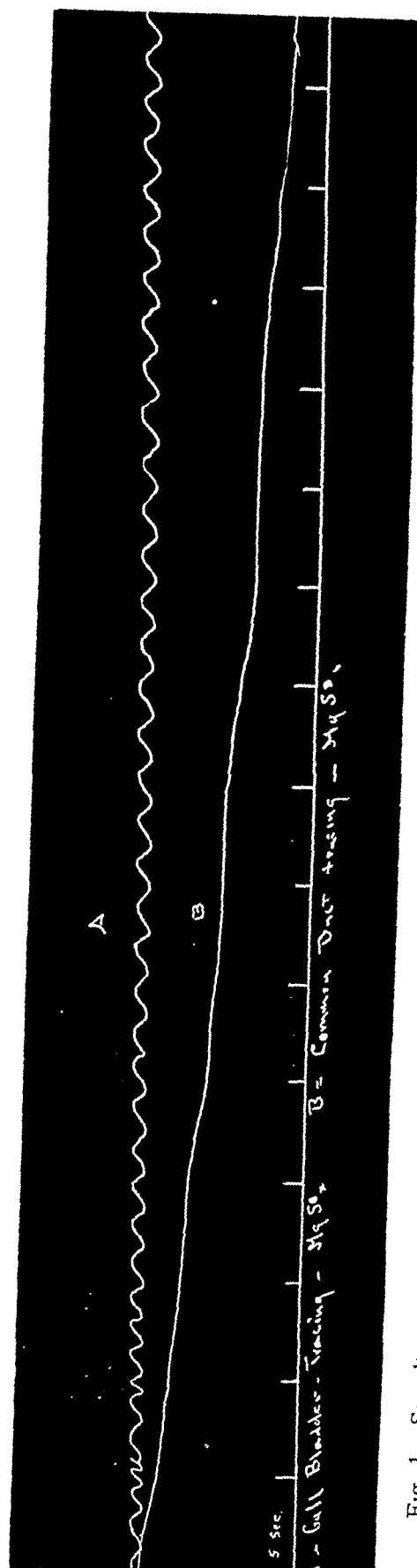


Fig 1—Simultaneous tracings of pressure changes in the gallbladder and common duct following duodenal instillation of concentrated magnesium sulphate. Tracing A indicates no appreciable change in gallbladder pressure, Tracing B shows decrease in intraductal common duct pressure.

When concentrated magnesium sulphate was applied, there was no change in the rate or curve. If a relaxation followed such an application, one would expect the altered curve to take the general form indicated by the dotted lines *C* in Figure 2. If a contraction had followed such application, the curve would take the general form illustrated by the Curve *B*.

#### FLOW OF GALLBLADDER BILE AND OF LIVER BILE

The common duct was catheterized with a fine dropping cannula and the normal biliary flow ascertained in drops for five minute intervals. Five c.c. of bile was carefully removed by an aspiration needle from the gallbladder and replaced by 5 c.c. of strong methylene blue bile solution in order to have an indicator of gallbladder bile, should it be expelled through the cannula. Drops from the cannula were recorded electrically on the revolving smoked drum. Five cubic centimeter amounts of 25 per cent magnesium sulphate, of 5 per cent peptone, of 5 per cent meat extract, of 0.4 per cent hydrochloric acid, and of 0.4 per cent sodium hydroxide were injected into the duodenum by needle through the bowel wall and the biliary flow was registered on the drum. Return to normal flow occurred usually one half hour before another substance was injected. Ether anesthesia was maintained as evenly as possible. This procedure was carried out in eight animals. Three representative findings are given in Table 2. Figure 3 gives the curves of these effects for Animal 1.

The data show an increased biliary flow on injection of acid, meat extract, peptone and magnesium sulphate, with increasing amounts in the order named. There was only moderate increase in the flow following the magnesium sulphate and practically none with the alkali. The earliest augmentation was noted with the acid and the most delayed with the peptone. The bile secreted was that characterized as "liver bile," a thin yellowish fluid of low specific gravity. These results conform quite well with Okada's findings in animals with biliary fistula and in feeding by stomach. There were variations noted in the bile flow with changes in the respiratory rate, depth of anesthesia, with peristalsis and at times suggestive of cumulative effects of the substances injected. In no case, however, was gallbladder bile expelled or was there any evidence to indicate contraction of the gallbladder. Crohn, Reiss, and Radin,<sup>38</sup> in a recent article, report that they also failed to see any evidence of gallbladder bile being discharged even during active digestion, and they found no substance capable of causing expulsion of the bile from the gallbladder when applied to the

38 Crohn, B. B., Reiss, J., and Radin, M. J. Experiences with Lyons Test (Magnesium Sulphate Lavage of the Duodenum). *J. A. M. A.* **76** 1567-1571 (June 4) 1921.

duodenal mucosa. They were led to believe that the gallbladder was decidedly an inactive organ that took little action in the physiologic production, storage or expulsion of the bile. In the experimental work herein recorded, the only instance in which gallbladder bile was obtained from the common duct cannula, except on forcible mechanical expression from the gallbladder, occurred on introduction of 200 cc of 0.4 per cent hydrochloric acid into the duodenum. Confirmatory

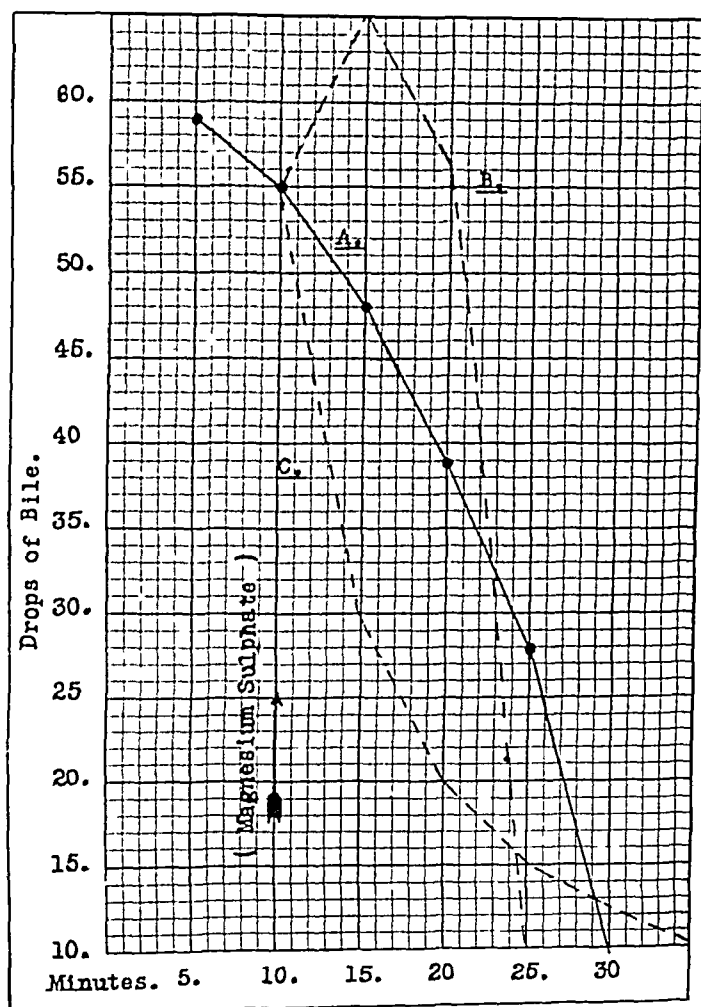


Fig 2—Effect of application of concentrated magnesium sulphate on rate of biliary flow. A, rate of flow; B, curve illustrating rate following contraction; and C, curve illustrating rate following relaxation.

of the work of Okada, there occurred in every case a long enduring, pronounced increase of flow of thin, dilute yellowish bile. In three of eight instances, however, the flow throughout was stained with methylene blue, indicative of gallbladder bile under the conditions of the experiment. In no other instance was gallbladder bile seen in the flow nor was there any visible manifestation of any contraction of the gallbladder. Figure 4 shows the long enduring biliary flow follow-

ing the introduction of 200 cc of 0.4 per cent hydrochloric acid into the duodenum and the similarity of its flow to the pancreatic secretion under the same stimulus

The experimental data herein presented fail to indicate that magnesium sulphate caused any contraction of the gallbladder or produced any expulsion of its bile content. Recently, Dunn and Connell<sup>39</sup> in a human subject, with duodenal fistula and from whom the gall-

TABLE 2—ESTIMATION OF TIME OF SECRETION OF BILE IN THE DOG

	Time, Minutes	Amount in Drops from Fine Cannula			Remarks
		Dog 1	Dog 2	Dog 3	
Magnesium sulphate					
Before injection	5	28	32	23	Thin yellow bile
	10	26	35	21	No gallbladder bile
After injection	5	28	29	20	
	10	36	33	28	
	15	32	40	27	
	20	25	32	22	
	25	25	{53}	19	
	30	22	{ }	14	
Peptone solution 5 per cent					
Before injection	5	22	39	22	Thin yellow bile
	10	20	35	19	No gallbladder bile
After injection	5	22	32	18	
	10	24	38	17	
	15	34	53	28	
	20	38	58	27	
	25	26	32	22	
	30	24	28	27	
Meat extract 5 per cent solution					
Before injection	5	25	32	18	Thin yellow bile
	10	19	30	14	No gallbladder bile
After injection	5	39	44	10	
	10	38	57	11	
	15	33	54	12	
	20	22	42	6	
	25	19	35	6	
	30	19	26	12	
Acid hydrochloric, 0.4 per cent					
Before injection	5	22	26	17	Thin yellow bile
	10	26	24	22	No gallbladder bile
After injection	5	42	38	56	
	10	48	58	66	
	15	36	44	61	
	20	34	28	42	
	25	28	31	30	
	30	19	26	28	
Alkali, sodium hydroxid 0.4 per cent					
Before injection	5	18	24	23	Thin yellow bile
	10	22	20	17	No gallbladder bile
After injection	5	12	17	22	
	10	14	26	19	
	15	20	29	12	
	20	28	34	16	
	25	18	22	19	
	30	21	12	20	

bladder and common duct had been removed, were able to get the increased biliary flow and the sequence of "A, B, C Bile" from the injection of magnesium sulphate either into the stomach or into the duodenum. This sequence, according to Lyon's theory, depended upon

39 Dunn, A. D., and Connell, K. Report of a Case of Hepatoduodenostomy, With Some Observations on the Lyon-Meltzer Method of Biliary Drainage, J. A. M. A. 77 1093-1096 (Oct. 1) 1921

the integrity of the gallbladder and the common duct and the expulsion of then contained bile under the effect of this concentrated magnesium sulphate solution

#### FUNCTION OF THE GALLBLADDER

It seems quite evident that the major part of the biliary secretion, the digestive fluid at least, is produced by hormone stimulation to meet the demands of digestion and in a manner identical with that con-

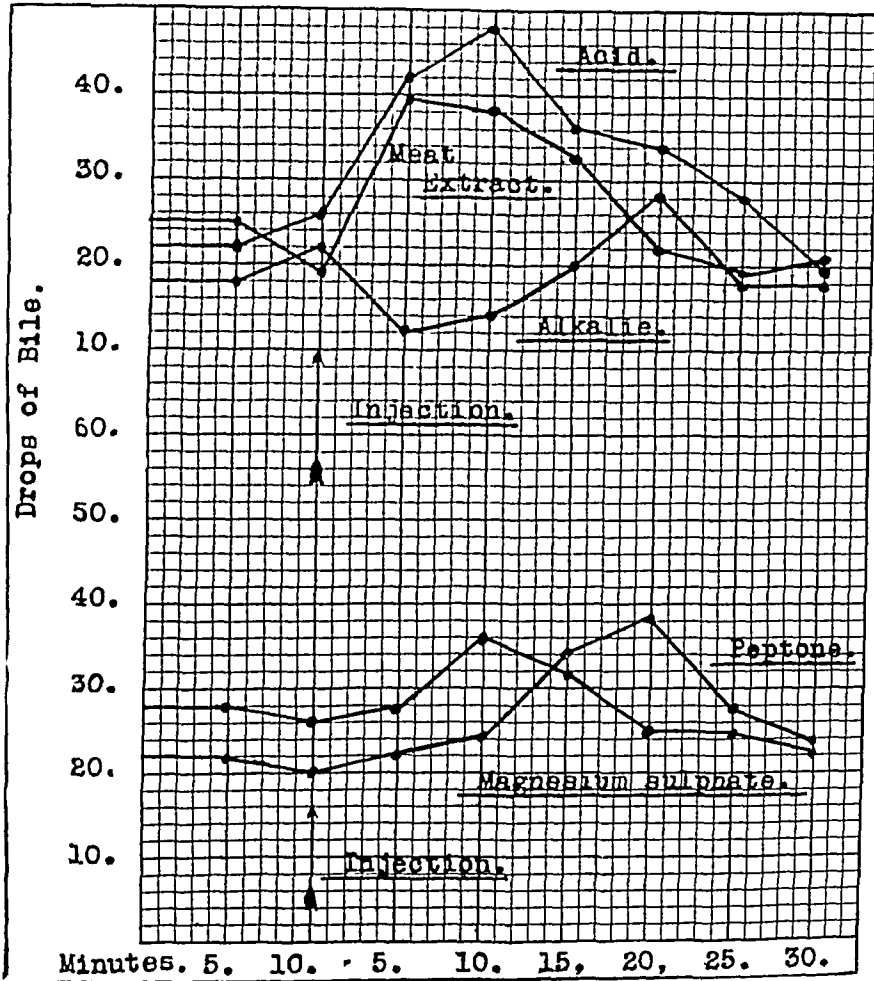


Fig 3—Effects of injection of acid, meat extract, alkalis, peptone and magnesium sulphate on rate of biliary flow

trolling the pancreatic secretion The period of most abundant bile production seems to coincide with the passage of the acid chyme into the intestine, and the liver continues to produce it as long as the digestive functions demand it The smaller portion of the biliary flow, the continuous secretion, finds its way into the gallbladder and is there stored up until active digestive processes allow its evacuation As a reservoir, the gallbladder has been said to be poorly adapted mechanically for such a function, both because of its small relative capacity to the large amount secreted during the twenty-four hours and also because

of its lack of inherent, efficient propulsive powers Mayo<sup>40</sup> has indicated that its storage capacity is only from one fortieth to one fiftieth of the twenty-four-hour secretion, and Mann<sup>36</sup> states that it can afford storage for about the amount secreted in one-half hour of active liver function

Under normal conditions, one does not meet with a distended gallbladder, distended as that organ may become under certain pathologic or mechanical conditions In common duct obstruction we may see a tense well-filled gallbladder, but one does not encounter the huge

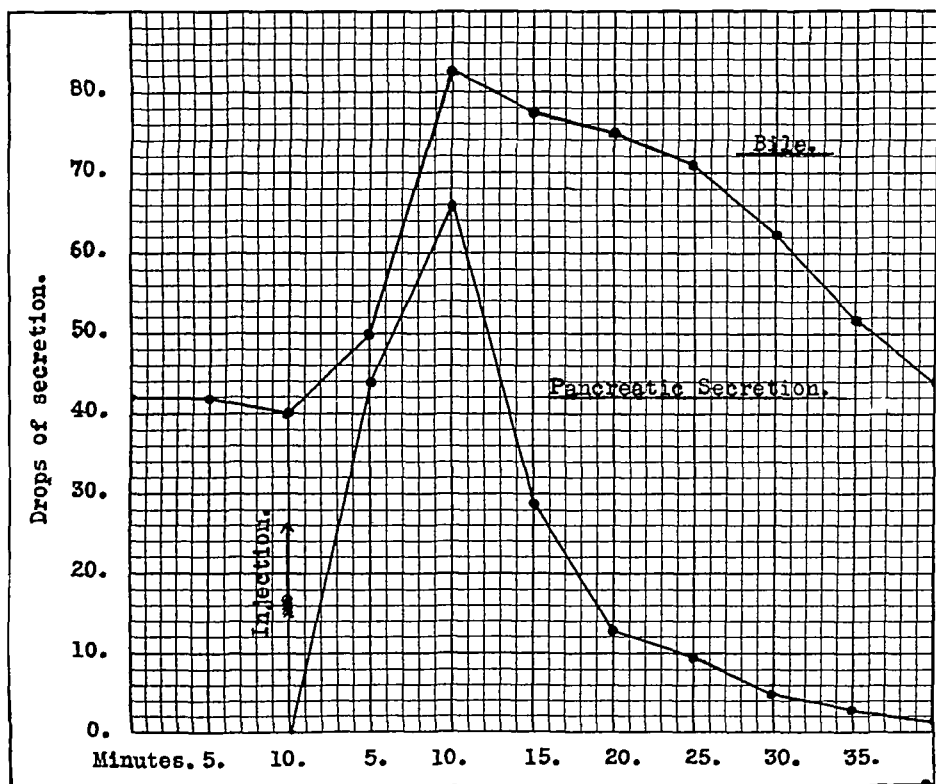


Fig 4—Comparison of biliary flow and pancreatic secretion following the introduction of 200 cc of 0.4 per cent hydrochloric acid into the duodenum

distended bladder This is usually explained by saying that the storage of bile ceases when the biliary pressure is equal to the secretory pressure of the liver, usually given as 350 mm of water The liver at this pressure does not cease to secrete bile, but this, probably, is the pressure at which the bile secreted escapes from the obstructed bile ducts into the blood stream at the margins of the liver lobules The large distended gallbladders are encountered in cystic duct obstruction in which the gallbladder is distended, not with the bile from the liver, but with its own secretion, produced as a result of a pathologic condition of the gall-

bladder wall. On the other hand, increase in pressure in the fundus of the gallbladder tends to prevent entry or exit of bile to, or from, the gallbladder beyond a certain pressure by kinking the S-shaped portion of the neck of the gallbladder and cystic duct. Inability to express bile from the gallbladder by manual pressure may or may not be indicative of a pathologic condition of the bladder. One can fill the gallbladder with fluid to a very high pressure, almost to the point of rupture, and get no flow from the cystic duct, straightening out the neck and the cystic duct by a little pressure on the S-shaped portion will immediately produce an abundant flow of bile. One can readily see how this S-shaped portion, neck or ampulla of the gallbladder, prevents the gallbladder from becoming overdistended and also how an inflammatory condition of the gallbladder and biliary passages might so modify the configuration of the neck, ampulla, cystic duct and leaflets as to make it a nonfunctioning gallbladder.

In a recent article, Rous and McMaster<sup>41</sup> have given us an insight into another function of the gallbladder and biliary passages. Using bile pigment in the bile as the criterion, they found a concentration of bile to ten times the normal in gallbladders which had been emptied and allowed to fill *in vivo*. In distended bladders, the concentration was about nine times the normal in the twenty-four hours. Mere passage of bile through the gallbladder concentrated the bile from two to four times. This was done by the abstraction of water. The gallbladder was thus made a rather capacious organ not so much from its size as from its singular power of reducing the bulk of the fluid reaching it. By this concentrating power it was enabled to maintain the liver output between the periods of gastric activity. According to these men, the gallbladder and the ducts have opposite influences upon the bile. Stasis of bile, connected with or in conjunction with, the gallbladder, always results in a thick, black syrupy bile due to this concentrating effect of the gallbladder. On the other hand, stasis of bile unassociated with the gallbladder results in a thin "white bile" due to the diluting effect of a specific duct secretion. The ducts evidently have the power of secreting a characteristic fluid of their own even under pressures great enough to cause distention of their tough and inelastic walls, a secretion that is devoid of cholates even when the rest of the organism is heavily jaundiced.

As far as has been ascertained clinically, the removal of the gallbladder has resulted in no special detrimental effects. In the Mayo Clinic, cholecystectomized patients showing no untoward symptoms have been followed for more than fifteen years. Mann has kept cholecystectomized dogs for three and one-half years, and they appear to be normal.

<sup>41</sup> Rous, P., and McMaster, P. D. Concentrating Activity of the Gallbladder, *J. Exper. Med.* **34** 47 (July) 1921, Physiological Causes for the Varied Character of Stasis Bile, *J. Exper. Med.* **34** 75 (July) 1921.

as far as nutrition and outward appearances are concerned Judd and Mann have shown the great dilatation of the extrahepatic passages and the reduction of intraductal pressure with relaxation of the sphincter of Oddi following removal of the gallbladder Eisendrath and Dunlavy<sup>42</sup> and Haberer and Clairmont<sup>43</sup> have reported cases in which the incompletely removed cystic ducts have dilated to form structures similar to the gallbladder and which supposedly function like one Rost<sup>25</sup> has shown that animals subjected to cholecystectomy formed two groups (1) those with continent sphincters and with dilated bile ducts, the action of which was similar to that of a gallbladder, (2) those having incontinent sphincters and with little or no dilatation of the ducts In these there was a constant dribbling of bile into the duodenum During fasting periods, in certain of these animals, the biliary flow was so profuse as to be voided in the stools Rost has also found a decrease in the secretion of bile and pancreatic juice in cholecystectomized animals after a test meal or after the injection of large amounts of acid chyme into the duodenum

The gallbladder seems mechanically placed as a distensible pouch or bag interposed in a system of biliary tubes for the purpose of minimizing extremes of pressure within that system, as when bile comes too rapidly from the liver or when its passage into the duodenum is prevented by the sphincter of Oddi It is doubtful whether, under normal conditions, the intraductal or gallbladder pressure ever exceeds 350 mm of water, the pressure required for obstructive symptoms Forced movements of the abdominal muscles, of diaphragm and contiguous organs produced by excessive respiratory movements, struggling, vomiting, violent peristalsis, all undoubtedly produce fluctuations in pressure that are equalized by the gallbladder The production of mucus and the concentrating power of the gallbladder itself in contrast to the biliary passages are indicative of some distinctive and purposeful differentiation of that organ for present function or possibly of a function that is more actively important in the embryologic history of that structure The fact that on removal of the gallbladder no special detrimental effects develop clinically may also be indicative of the wonderful adaptability of the human mechanism to such an altered condition as well as confirmatory of any lack of present function One wonders whether the gallbladder is in the same category, with respect to function, as the vermiform appendix

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42 Eisendrath, D. M., and Dunlavy, H. C. The Fate of the Cystic Duct After Cholecystectomy, *Surg. Gynec. & Obst.* **26** 110 (Jan.) 1918

43 Haberer and Clairmont. Experimentelle Untersuchungen über das Verhalten des Cysticusstumpfes nach Cholecystectomie, *Arch. f. klin. Chir.* **73** 679 1904



## SUMMARY

1 Bile as a secretory product of the liver is produced probably through hormone stimulation associated with the production of acid chyme in the stomach. The height of biliary flow is coincident with the passage of the acid chyme into the duodenum.

2 There is a marked similarity between the curve of bile production and that of pancreatic secretion.

3 The smaller continuous secretion of the liver is stored in the gallbladder which acts as a reservoir, until evacuated by the demands of digestion. The storage capacity of the gallbladder is augmented by its remarkable concentrating power.

4 The S-shaped configuration of the neck and ampulla of the gallbladder prevents overdistention of the gallbladder. When overdistended it prevents the exit of bile. By altering the peculiar configuration of this portion of the gallbladder and cystic duct, inflammatory conditions may readily produce a nonfunctioning gallbladder.

5 The sphincter of Oddi, a definite muscle entity at the duodenal end of the common duct, sustains an absolute pressure of about 150 mm of water. The gallbladder undoubtedly equalizes the great fluctuations in this pressure due to movements of the abdominal muscles and contiguous organs. Cholecystectomy tends to produce a lowered intraductal pressure and a relaxed tone of the sphincter of Oddi. The sphincter is probably under reflex nervous control associated with the passage of acid chyme into the duodenum and with intrinsic movements of the duodenum itself.

6 Magnesium sulphate does produce a complete, local relaxation of the duodenal wall and the papillary sphincter, with reduction of the intraductal pressure. Relaxation is transient and is usually accompanied by a flow of bile from the orifice.

7 There was no evidence that concentrated magnesium sulphate produced any contraction of the gallbladder or any specific change in the gallbladder pressure. The augmented biliary flow from its application is probably due to the evacuation of the bile from the bile ducts as a result of sphincter relaxation and also to the stimulating effect of the salt upon the liver secretion.

8 Flow of bile from the gallbladder has been produced in certain cases by injection of large amounts of 0.4 per cent hydrochloric acid into the duodenum. This probably is the mechanism of its discharge at the beginning of digestion.

9 The production of mucus and the concentrating power of the gallbladder are suggestive of some purposeful differentiation of that structure, although its removal has been, in human beings, without any definite, clinically demonstrable deleterious effects.

# OBSERVATIONS ON THE NORMALLY DEVELOPING KNEE

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NEW ORLEANS

Since the original study of this series proved that there are so many possible sources of error from lack of proper appreciation of the appearance of normal joints at all ages, effort has been made to study the hip, knee and shoulder in a manner similar to the methods adopted in studying the elbow. The fact that there are more sources of error in interpreting the elbow than in any other joint in the body encouraged further study.

Francis Howard Williams, in 1902, made the following statement "The x-rays are of assistance in pointing out delayed union of the epiphyses and when we are familiar with the appearance to be expected of the epiphyses at different ages—that is to say, when we have made a physiological scale, we may find that we have gained a method of estimating the general condition of the younger patients in regard to their development" <sup>1</sup>

In the light of the foregoing statement, made twenty years ago, it is remarkable that no such systematic study has heretofore been published.

We can arrive at some idea of how varied are the ideas relative to the knee by quotations from the best authorities of different periods.

Jonathan Hutchinson may fairly be expected to express the best thought of his time on the subject. In a lecture before the Royal College of Surgeons, in 1894, he <sup>2</sup> states, in regard to the lower epiphysis of the femur, "There is no epiphysis of so much practical importance as the lower epiphysis of the femur. Theoretically, we might expect a separation to occur beyond the twentieth year. The epiphysis includes the whole articular surface, and its separation must imply injury to the synovial membrane." Hutchinson further calls attention to several valuable points which should be kept in mind by a surgeon dealing with this joint in the young: the adductor tubercle is at the upper limit of the epiphysis, and both heads of the gastrocnemius are attached to the epiphysis. Another statement is made, which is interesting in a general way, if not particularly bearing on the point in hand: "It was far easier to separate the epiphysis than to rupture the liga-

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1 Williams F H. Roentgen Rays in Medicine and Surgery, 1902, p. 459.

2 Hutchinson, Jonathan. Brit M J, March 31, 1894.

ments of the knee " When we compared the work of Hutchinson with that of Ross and Taylor, during the past ten years on sprains, we can appreciate how keen the observations of men like Hutchinson were. Another several years, and the infrequency of sprains will be appreciated.

J Hogarth Pringle<sup>3</sup> states "One (center) for the lower extremity (femur) appears shortly before birth and fuses with the diaphysis about the twentieth year.

In the tibia, the upper epiphysis, from which both the tuberosities and the tubercle are developed, begins to ossify at birth and joins the diaphysis at from the twenty-first to the twenty-fourth year.

There is sometimes a separate center for the anterior tubercle which shows at the eleventh or twelfth year.

In the fibula, the upper epiphysis begins to ossify about the fourth year and joins the shaft at the twenty-second to the twenty-fourth year " Reference to texts on the subjects of the appearance, development and ossification of the epiphyses of the knee is of interest. Quotations from some of the foremost texts will be of service.

In Gray's "Anatomy" it is stated that ossification appears within the lower epiphysis of the femur during the ninth month of fetal life, and is not complete within this center until the twentieth year, further, concerning the development of the patella, that this occurs from a single center which makes its appearance about the third year, that more rarely, this bone is developed by two centers placed side by side, and ossification is completed about the age of puberty.

In speaking of the tibia, it is stated that the center for the upper epiphysis appears before or shortly after birth, it is flattened in form and has a tongue shaped process in front which forms the tubercle, and the upper epiphysis of the tibia joins the shaft about the twentieth year.

In Piersol's "Anatomy," the statement is made that the lower epiphysis of the femur is joined by the age of 20 and often earlier, the patella is not fully formed until after puberty—perhaps not before the age of 18, the center of ossification for the upper end of the tibia appears usually during the last month of pregnancy, and the upper epiphysis extends farther down in front, to form the tubercle which may have a separate nucleus. According to Rambaud and Ranault, this is the usual occurrence, appearing at from 8 to 14 years, and quickly joining the epiphysis, and the upper epiphysis joins the shaft at about 19 or 20 years of age.

Scudder in his textbook on fractures says "The lower epiphysis of the femur, the largest epiphysis of the body, appears shortly before birth, attains a good size by 2 years of age, and unites with the diaphysis at from the twentieth to the twenty-third year " He states regarding

<sup>3</sup> Pringle, J. Hogarth. *Fractures*, 1910, p. 154.

the tibia "The epiphysis of the upper end of the tibia appears at about the first year and unites to the shaft at the twentieth to the twenty-second year "

Cotton, in his work on "Joint Fractures and Dislocations," avoids mention of the age at which ossification of the epiphyses of the lower end of the femur and the upper end of the tibia takes place

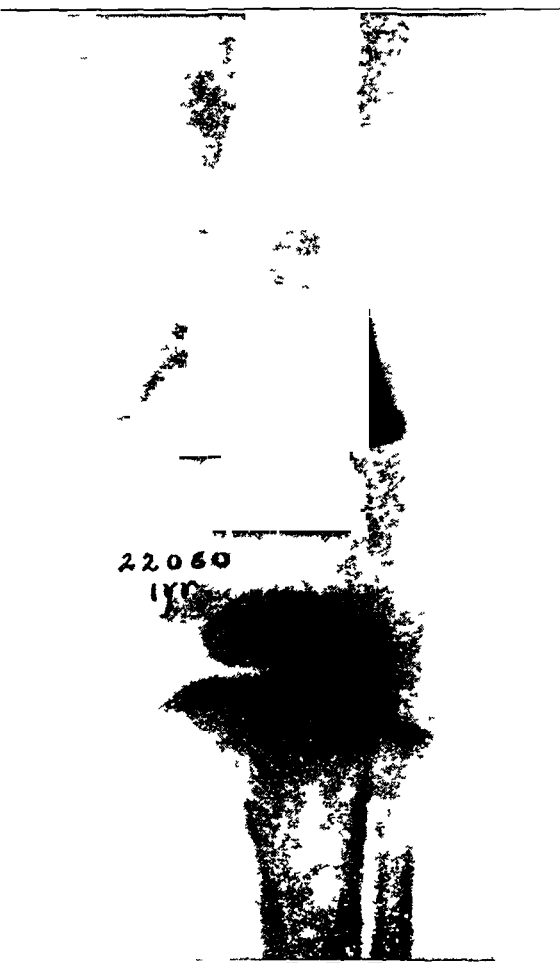


Figure 1

Fig 1—Normal knee, age 1 year

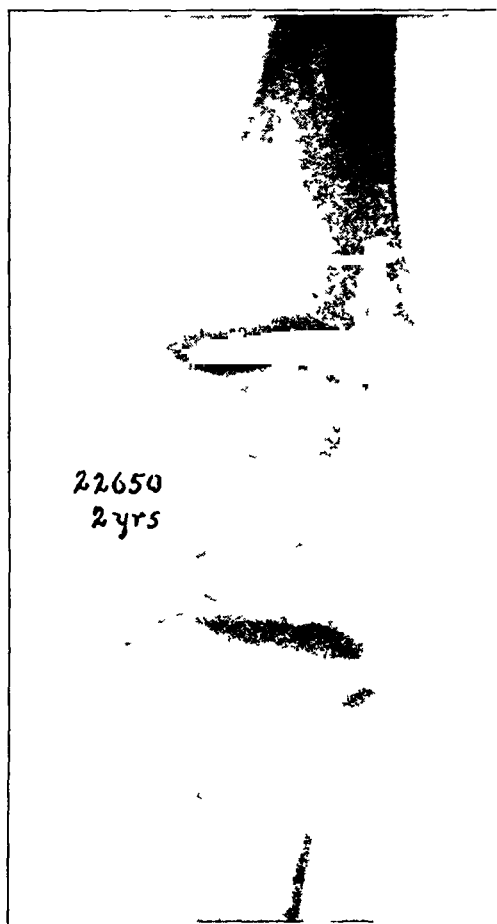


Figure 2

Fig 2—Normal knee, age 2 years

Roberts and Kelly write "The lower epiphysis of the femur includes the entire articular surface of the lower end of the bone It is the largest epiphysis of the body, and unites with the diaphysis from the twentieth to the twenty-first year The tubercle and upper epiphysis of the tibia ossify from a single centre, and unite with

the diaphysis from the twenty-first to the twenty-second year. The tubercle at first is cartilaginous, and ossification extends downward from the epiphysis as a long tongue-shaped projection."

## OBSERVATIONS

From a review of the literature, it would seem that all are agreed that the lower epiphysis of the femur appears before birth, but there does not seem to be a unanimity of opinion as to the time of complete ossification and union with the shaft. Such statements as "about the twentieth year or earlier, twentieth to twenty-third year, and up to the twenty-fifth year" are found in the anatomies and texts commonly referred to.

From our observations, it seems justifiable to state that complete ossification and union of the lower epiphysis of the femur with the

TABLE 1—OPINIONS REGARDING TIME OF OSSIFICATION OF UPPER  
EPIPHYSIS OF TIBIA

Author	Beginning Ossification	Complete Ossification
Pringle	At birth	21st to 24th year
Gray	Before or shortly after birth	About 20th year
Piersol	During last month of pregnancy	About 19th or 20th year
Scudder	About first year	20th to 21st year

TABLE 2—OPINIONS REGARDING TIME OF OSSIFICATION OF LOWER  
EPIPHYSIS OF THE FEMUR

Author	Beginning Ossification	Complete Ossification
Hutchinson		Beyond 20th year
Pringle	Shortly before birth	About 20th year
Gray	Ninth month fetal life	20th year
Piersol		20th year or earlier
Scudder	Shortly before birth	20th to 23d year
Cotton		No mention made of age of ossification
Roberts and Kelly		20th to 21st year
Stimson		Epiphysis may not unite with shaft before 25th year

shaft takes place between the eighteenth and nineteenth year constantly. In some instances, complete ossification and union with the shaft have taken place during the fifteenth year (Fig 14 A), and again a similar condition has been noted during the sixteenth year (Fig 16).

It may be argued that development occurs sooner in tropical and semitropical climates. This cannot be disputed, but it would prove interesting if our observations should be either verified or corrected for other climatic conditions.

There is a decided divergence of opinion in the literature as to the time of complete union of the upper epiphysis of the tibia. From

Table 1 and quotations in the portion of the paper dealing with this phase of the question, it can be seen that union is supposed to take place at any time between the nineteenth and twenty-fourth years

In this series of observations, the epiphyseal line cannot be made out after 18 years and 11 months (Fig 18)

Aside from this fact, the upper epiphysis of the tibia presents several interesting phenomena which are worthy of more than passing

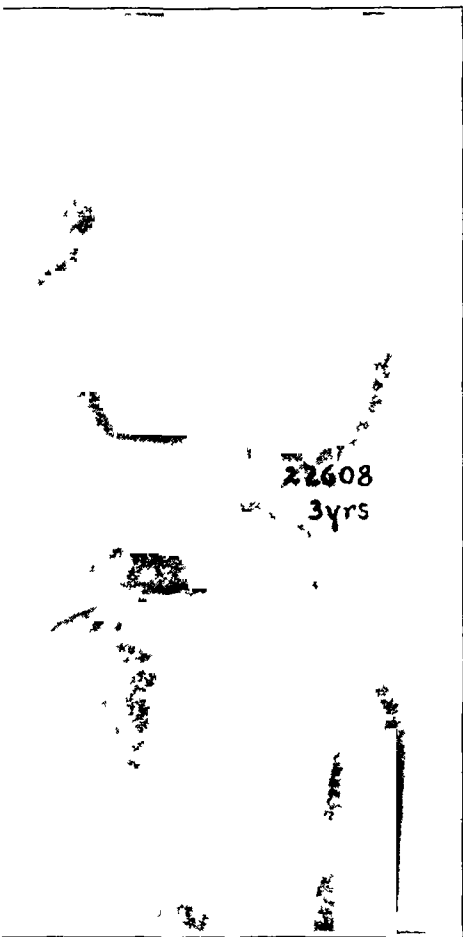


Figure 3

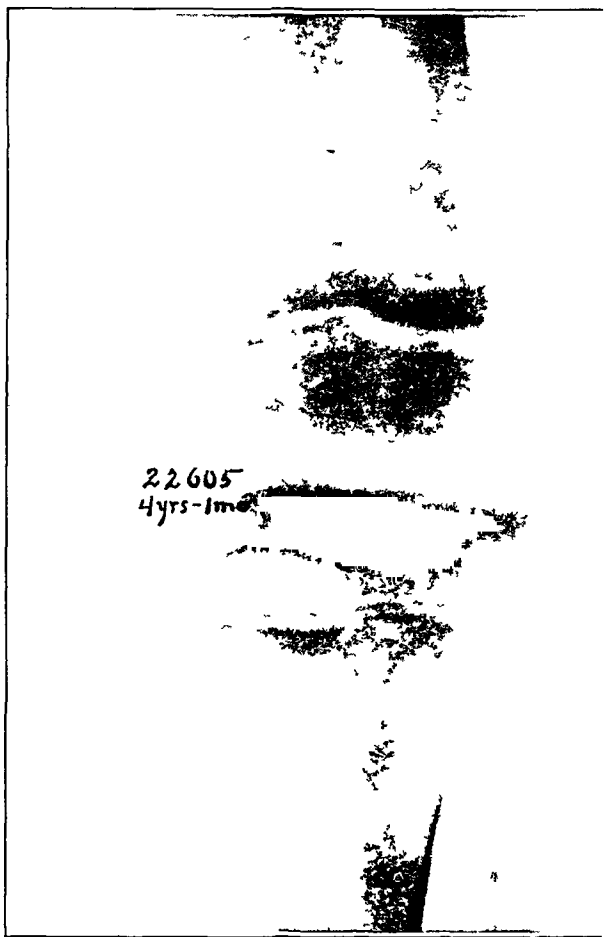


Figure 4

Fig 3—Normal knee, age 3 years

Fig 4—Normal knee, age 4 years

comment It should be noted that normally the upper epiphysis of the tibia is in the same perpendicular planes as the lower epiphysis of the femur, and any deviation laterally should arouse suspicion that there is a displacement of one of the two

Second and most important, the tubercle of the tibia is a downward projection of the upper epiphysis of the tibia which makes its appear-

ance about the eleventh year. At times the projection seems widely separated from the shaft. This may give rise to the opinion that there is a fracture of the tubercle of the tibia, or "spur" formation. The latter was the interpretation which was made by a roentgenologist recently (Figs 12 B and 14 B). At times, the tubercle seems to develop from two separate centers of ossification, thus simulating a fracture within the tubercle itself (Fig 15).

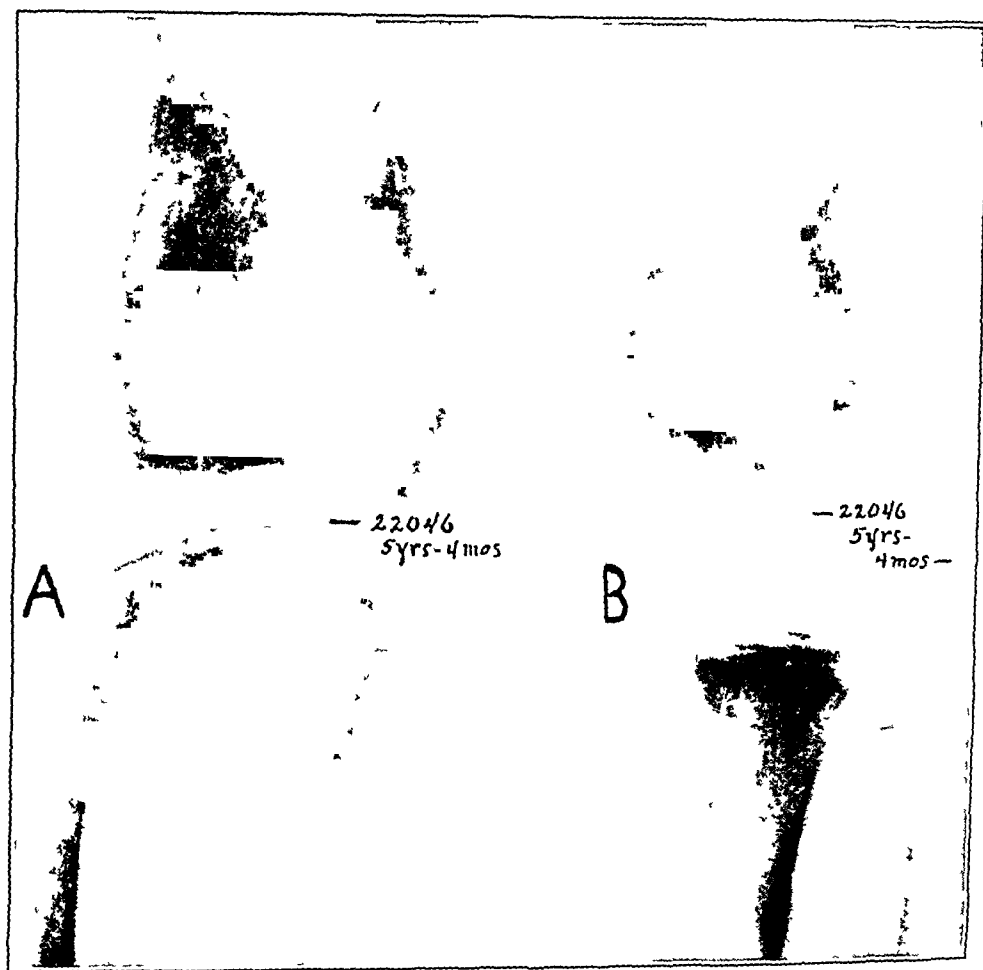


Fig 5—Normal knee, age 5 years and 4 months

The tubercle is completely joined to the shaft by the nineteenth year.

The patella, according to Gray, is completely ossified "about the age of puberty." The time of the appearance of the patella is given by Gray as "about the third year."

Piersol says that it is "not fully formed until after puberty and probably not until the eighteenth year." The patella is noted in this study for the first time during the fifth year (Fig 5 B). It makes its appearance just opposite the epiphyseal line of the lower end of the

femur The patella presents the most variable appearance of all structures about the knee, as evidenced by Figures 5 *B*, 6 *A* and 8 At times, the patella seems to ossify through two centers within cartilage (Fig 8) The development is progressive, but the relative position of the joints of development is unchanged, that is, the middle is opposite the original site of the epiphyseal line At about 14 years, the patella seems to have reached its full bony development—*seems* because it is difficult to say what the ultimate size will be in a par-



Fig 6—Normal knee, age 6 years and 6 months

ticular case It can be asserted that by this time it possesses the contour, and relative to the surrounding structures, a full development for the bone

The upper epiphysis of the fibula is not evident before the fifth year At this time, it is represented by a small rounded center of ossification superimposed on the diaphysis of the fibula In some instances, it has become completely ossified by the fifteenth year (Fig 14 *A*) This union is not constant until the end of the eighteenth year (Figs 17 and 18) This epiphysis presents no unusual or interesting feature



## INTERPRETATION OF ROENTGENOGRAMS OF NORMAL KNEES

At 1 year of age, there is one epiphysis for the lower end of the femur and one for the upper end of the tibia. No epiphysis of the upper end of the fibula is apparent (Fig 1). The epiphysis of the lower end of the femur is about two thirds the size of the diaphysis, and it occupies the midplanes of the lower end of the shaft. The

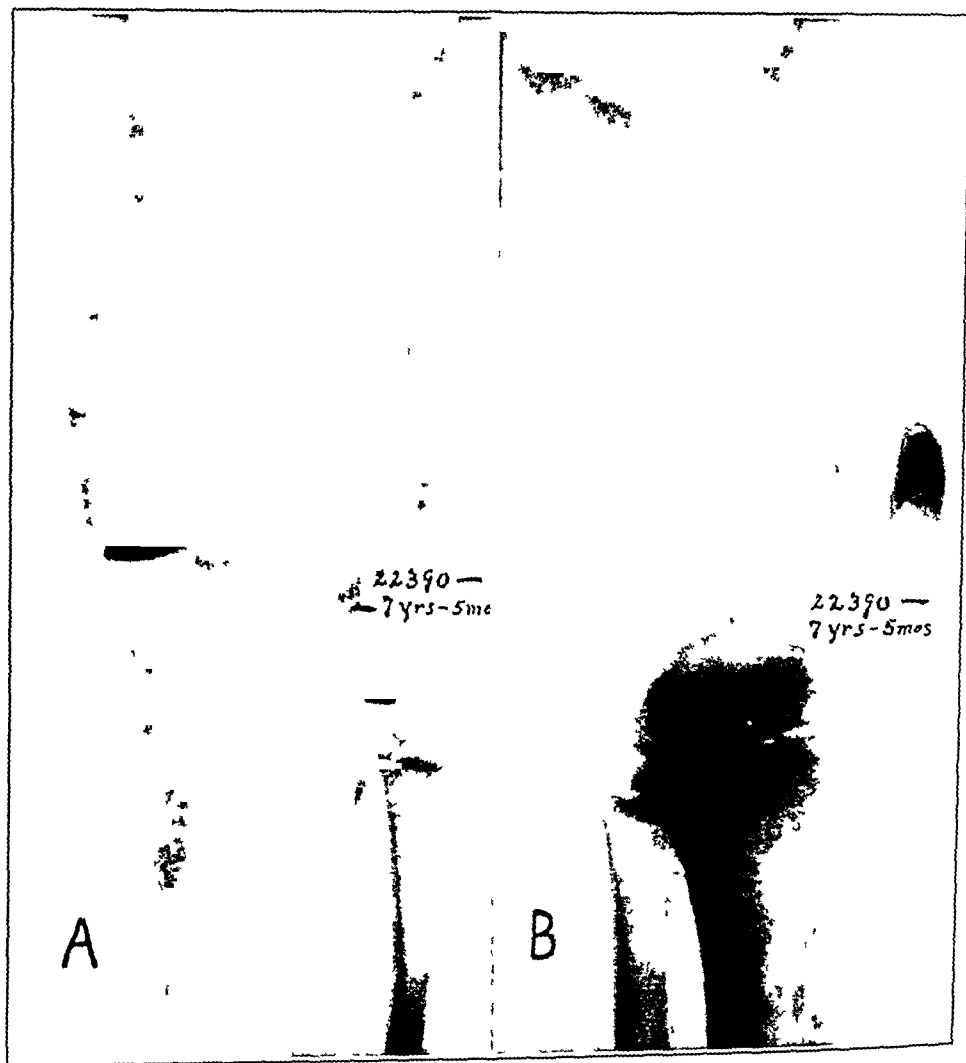


Fig 7—Normal knee, age 7 years and 5 months

epiphysis of the upper end of the tibia is about the same size as that of the lower epiphysis of the femur, and is in the same perpendicular planes roentgenologically.

At 2 years of age (Fig 2), the appearance is similar to that at 1 year, except for a relative increase in size.

At 3 years of age (Fig 3), the epiphyses for the lower end of the femur and the upper end of the tibia have increased relatively in the same proportion as the diaphyses. No epiphysis of the upper end of the fibula is evident at this time.

At 4 years of age (Fig 4), the lower epiphysis of the femur shows marked evidence of the developing intercondyloid space and occupies three fourths of the lower aspect of the diaphysis of the femur. There is still no evidence of the epiphysis for the upper end of the fibula. The upper epiphysis of the tibia has not increased in the same ratio as that of the femur.

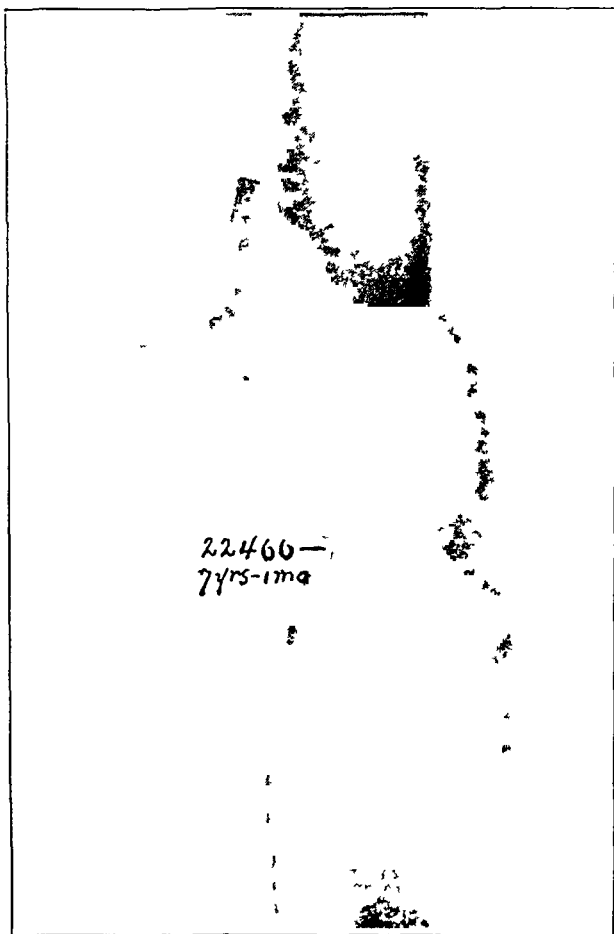


Fig 8—Normal knee, age 7 years and 1 month

At 5 years and 4 months (Fig 5 A), the lower epiphysis of the femur apparently occupies entirely the lower portion of the femur. A small ossifying epiphysis is evident over the upper end of the fibula. Just at the level of the lower epiphyseal line of the femur and anterior to it, we see a small shadow of ossification within the patella (Fig 5 B).

At 6 years and 6 months (Figs 6 A and B), the patella and the epiphysis for the upper end of the fibula have increased very much in size.

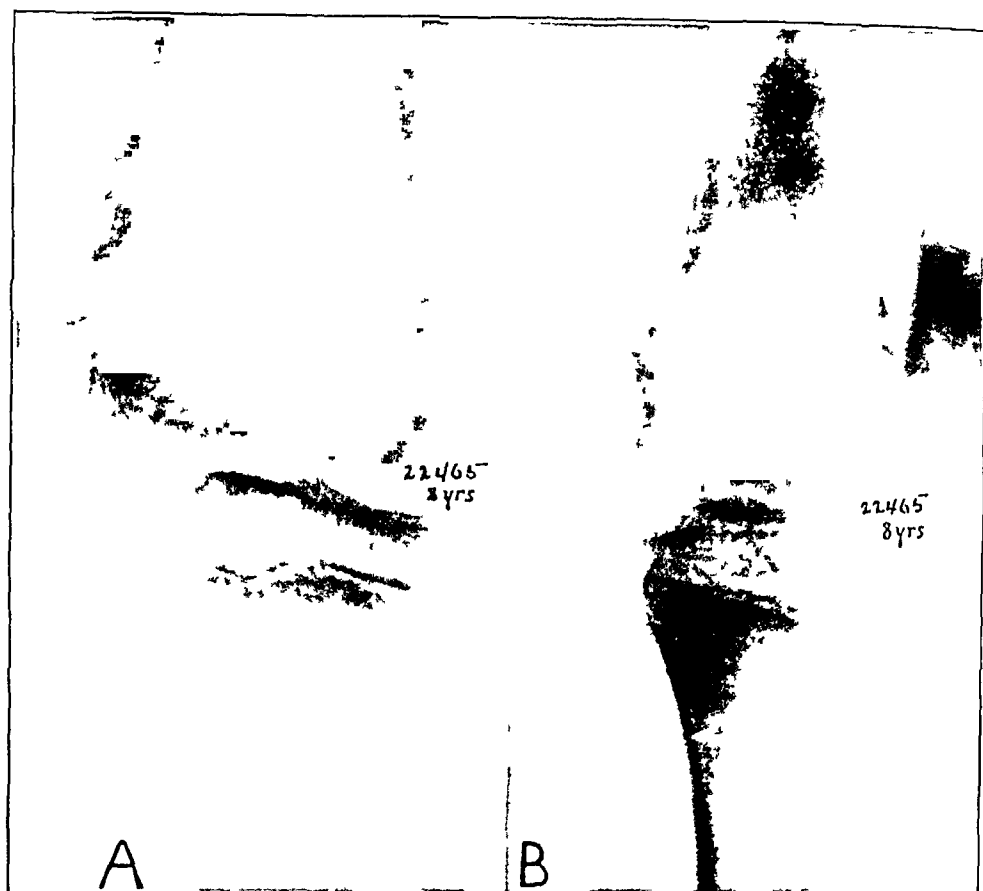


Fig 9—Normal knee, age 8 years

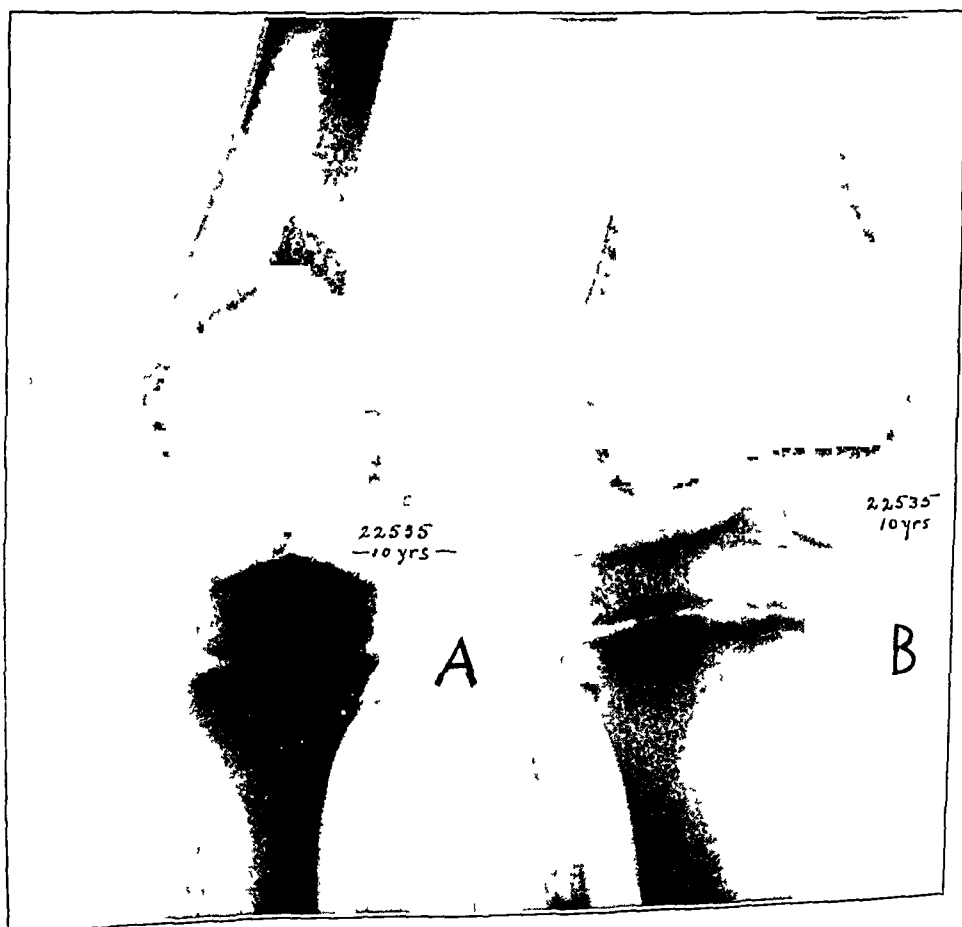


Fig 10—Normal knee, age 10 years

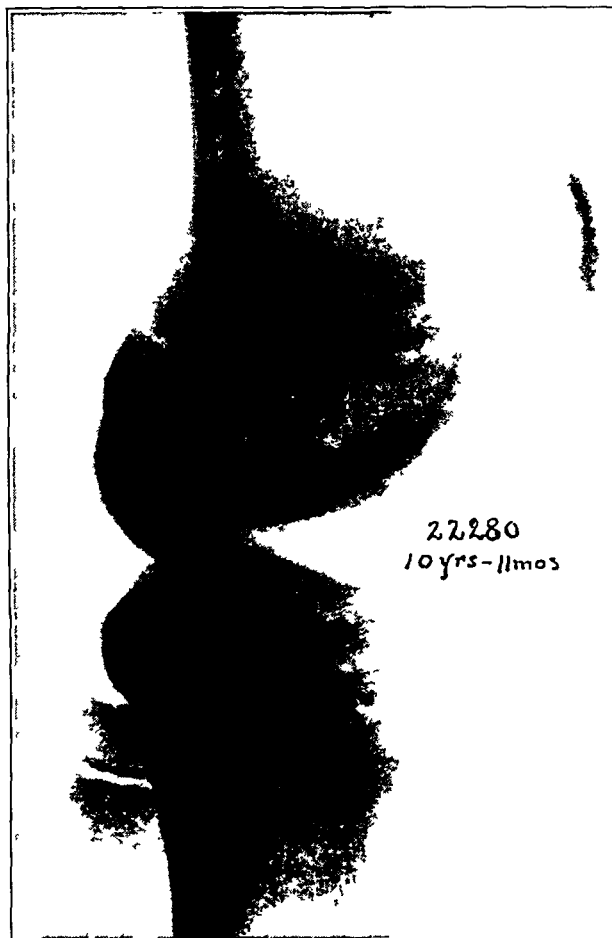


Fig 11—Normal knee, age 10 years and 11 months

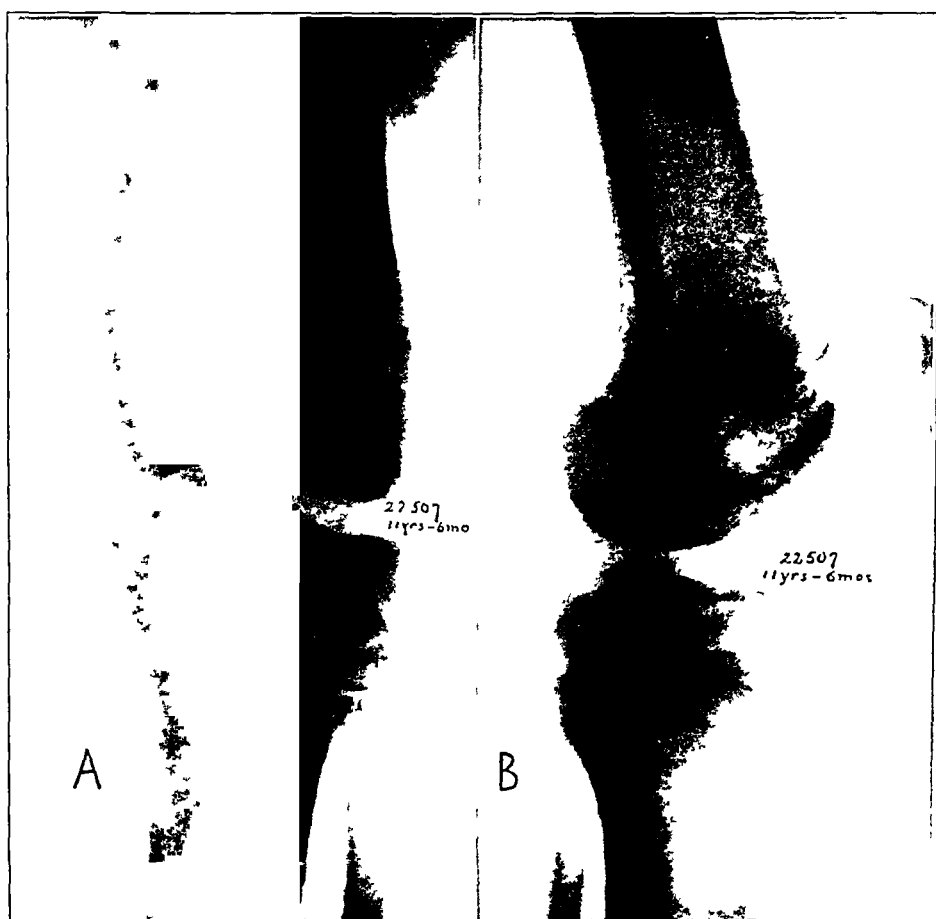


Fig 12—Normal knee age 11 years and 6 months

At 7 years and 5 months (Figs 7 *A* and *B*) all of the epiphyses have increased in size, the lower epiphysis of the femur occupying the entire lower portion of the diaphysis. The upper epiphysis of the fibula occupies two thirds of the diameter of the fibular diaphysis.

At 7 years and 5 months (Fig 7 *B*), the patella has ossified to a marked extent as compared to that pictured in Figure 8, at 7 years

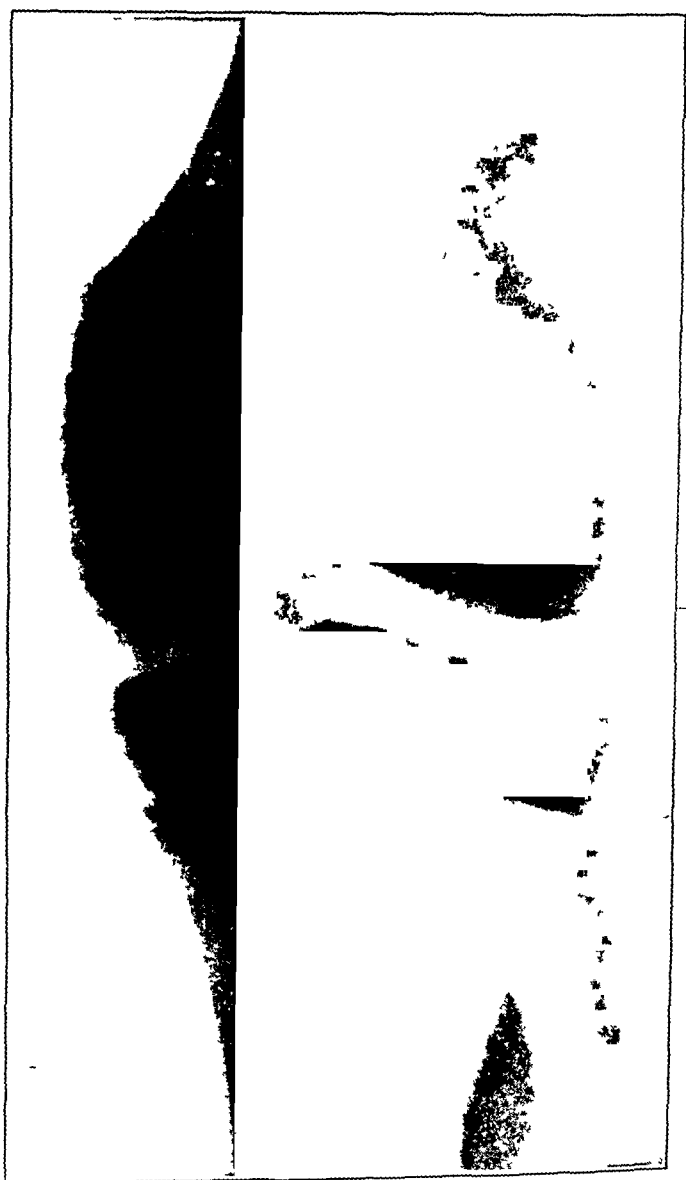


Fig 13—Normal knee, age 12 years and 8 months

There is evidence of an upward projection within the upper epiphysis of the tibia, differentiating the attachment for the crucial ligament, and also depressions for the semilunar cartilages.

The picture at 7 years and 1 month (Fig 8) shows very slight ossification within the patella. The ossification which has taken place seems to be developing from two centers.

At 8 years of age (Fig 9 *A* and *B*), there is a marked increase in the size of the epiphyses and a closer apposition between the epiphyses and the respective diaphyses. The patella is approximately twice the size of that in the preceding picture. It is interesting to note the amount of development of the patella in the period from 6 to 8 years. At 8 years of age (Fig 9 *A*), for the first time, we begin to see a depression for the semilunar cartilage and evidence of spines for the insertion of the crucial ligament are evident in the developing upper epiphysis of the tibia.



Fig 14—Normal knee, age 14 years and 8 months

At 10 years of age (Fig 10 *A* and *B*), there is a close approximation between the lower end of the femur and its epiphysis, but no true ossification has taken place between the shaft and the epiphysis. The depressions for the semilunar cartilages have deepened. There is a proportionate ossification in the upper epiphysis of the fibula and the patella. There is still no evidence of the tubercle of the tibia.

At 10 years and 11 months (Fig 11), all of the epiphyses continue to increase in size. There seems to be a projection downward

from the anterior surface of the upper epiphysis of the tibia, this being the first evidence noted of the tubercle of the tibia and its origin

At 11 years of age, little difference is shown except in the size of the epiphyses, if anything, the internal condyle seems to be larger than the external. There is no evidence of a tubercle of the tibia.

At 11 years and 6 months (Fig 12 *A* and *B*), the epiphyses for the upper end of the tibia and the upper portion of the fibula are com-

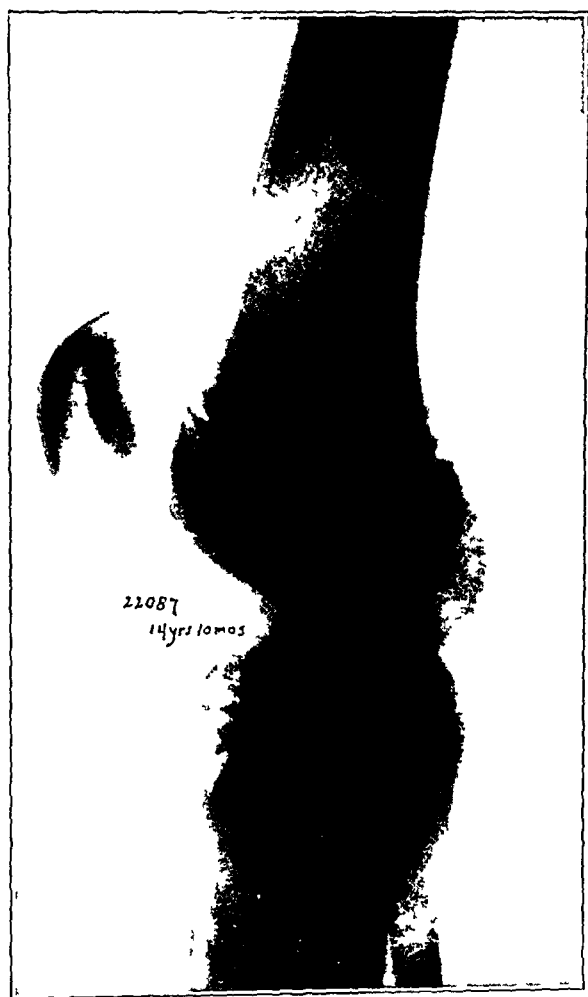


Figure 15

Fig 15—Normal knee, age 14 years and 10 months

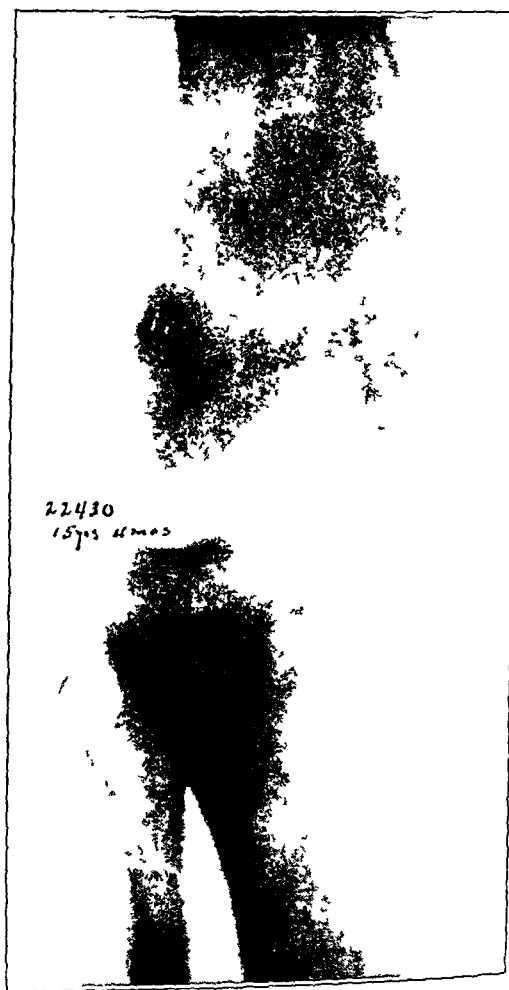


Figure 16

Fig 16—Normal knee, age 15 years and 4 months

pletely formed, but not united with the shaft. There is a projection downward on the anterior portion of the tibia, separated from the shaft of the tibia for possibly one fourth of an inch (6 mm), evidence of beginning ossification for the tubercle of the tibia.

At 12 years and 8 months (Fig 13), a close approximation of the shaft of the tibia is noted, but no ossification of the epiphysis and the shaft.

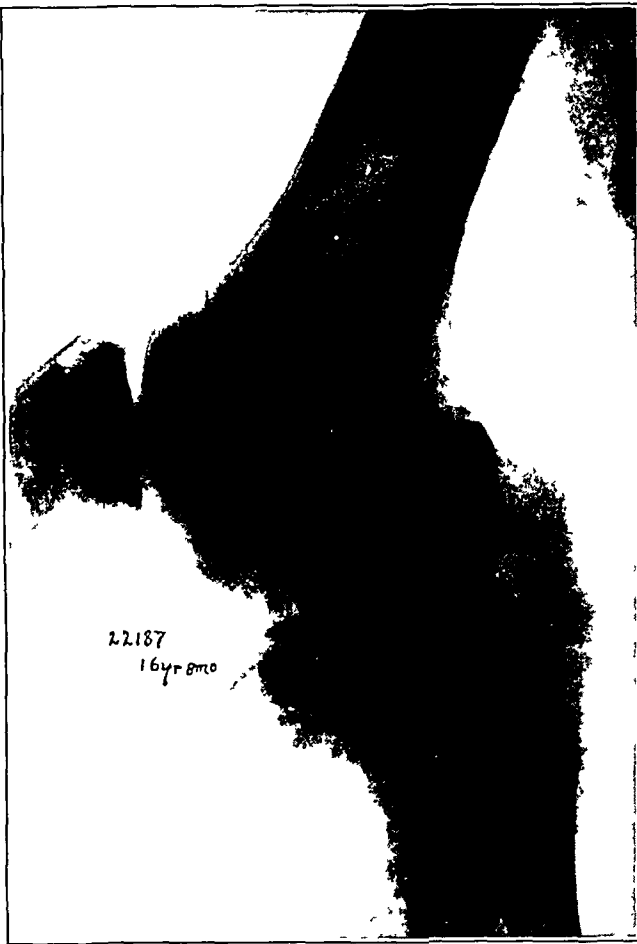


Fig 17—Normal knee, age 16 years and 8 months

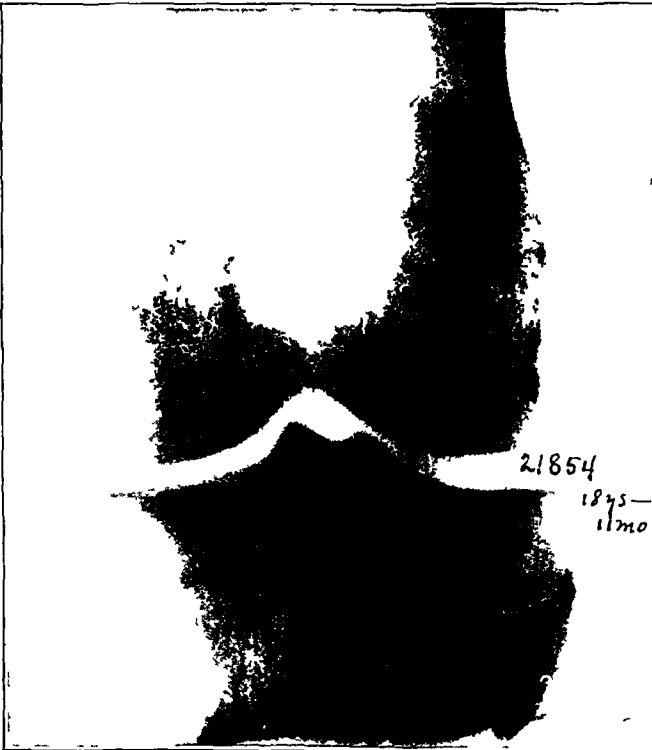


Fig 18—Normal knee age 18 years and 11 months



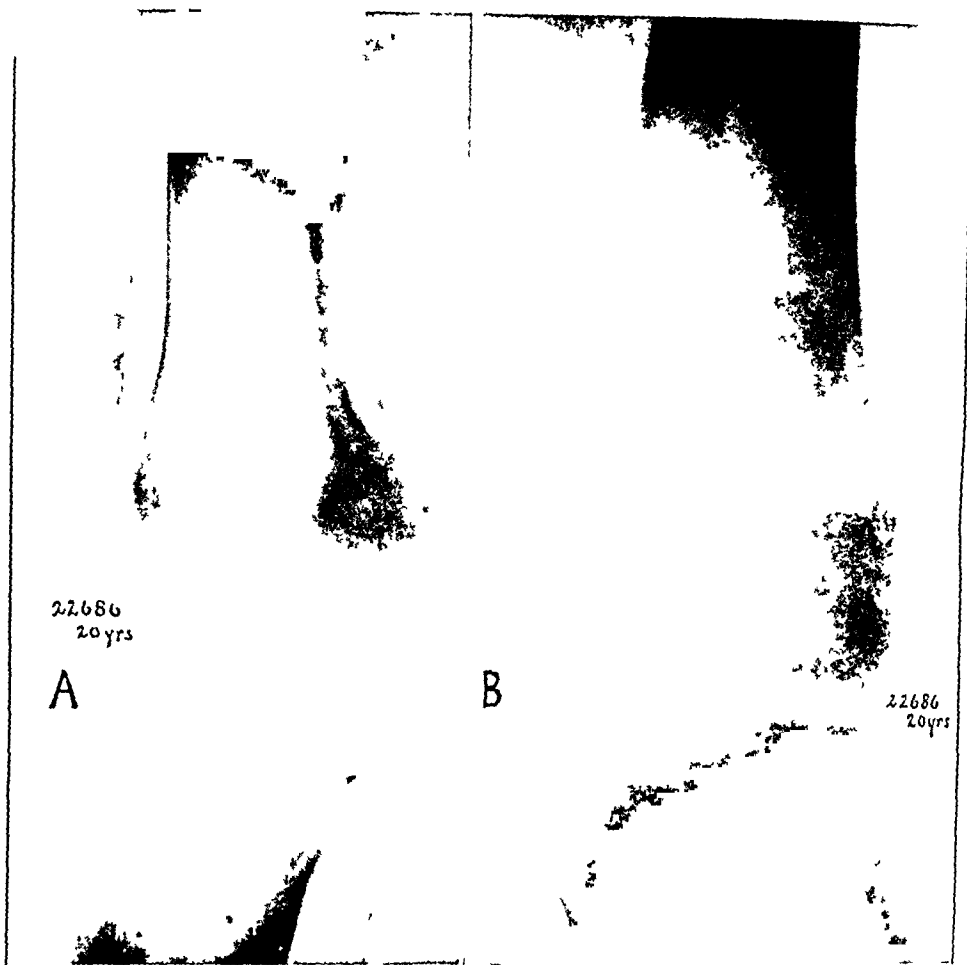


Fig 19—Normal knee, age 20 years

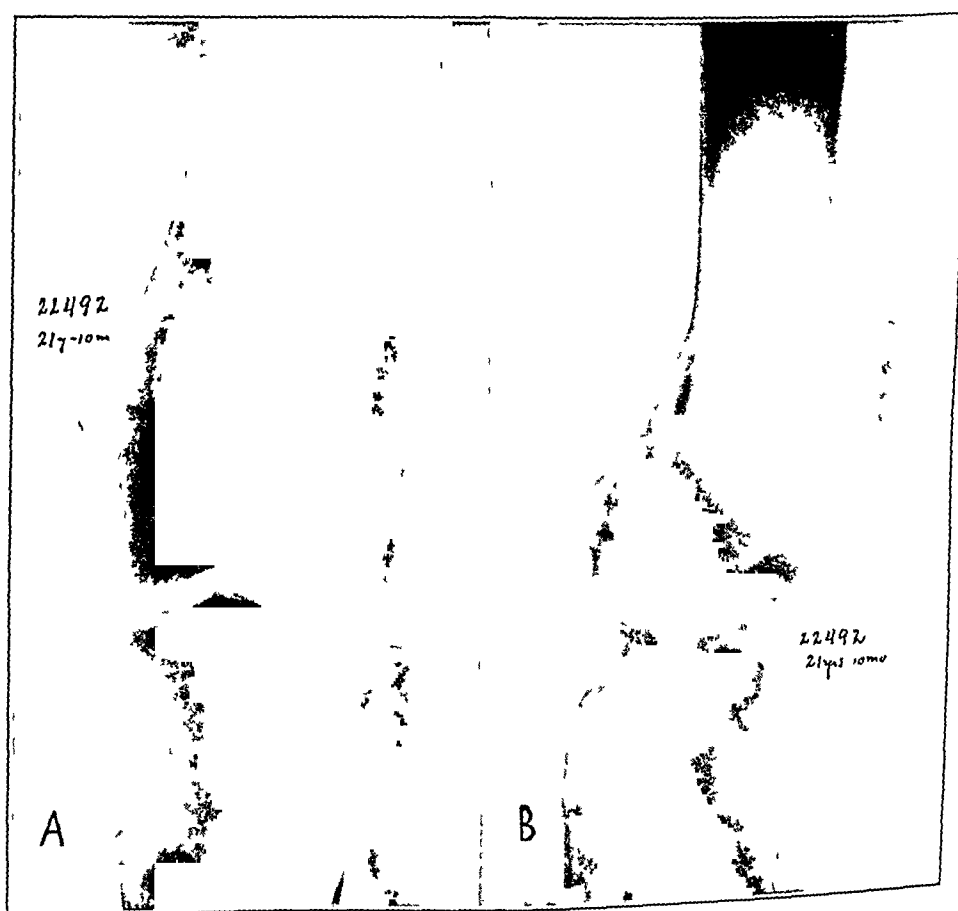


Fig 20—Normal knee, age 21 years and 10 months

At 14 years and 8 months (Fig 14 *A* and *B*), there is a complete ossification of all of the epiphyses of the knee. The lateral view (Fig 14 *B*) shows a projection downward from the upper epiphysis of the tibia, on the anterior aspect of the shaft. It is still separated from the shaft, but not so markedly as in preceding ages.

At 14 years and 10 months (Fig 15) there is incomplete ossification of the shafts to the epiphyses and the tubercle of the tibia apparently from two centers.

At 15 years and 4 months (Fig 16) there is a shadow, apparently the line of demarcation, but sufficiently ossified so that there is no clear space between the epiphyses and the shafts.

At 16 years and 8 months (Fig 17), the epiphyseal lines are present. The tubercle of the tibia is almost completely ossified.

At 18 years and 11 months (Fig 18), there is complete ossification of the epiphyses and union of the epiphyses and the shafts.

At 20 years (Fig 19 *A* and *B*), there is complete ossification.

At 21 years and 10 months (Fig 20 *A* and *B*), a picture similar to that at 20 years is presented.

#### SUMMARY

The epiphyses of the lower end of the femur and of the upper end of the tibia have attained the size of half the width of their respective diaphyses at 1 year.

There is evidence of ossification within these epiphyses at a much earlier time.

In one instance, we have a picture showing it at 7 weeks (lower epiphysis, femur).

During the first four years, no other epiphyses are evident roentgenologically.

At 5 years and 4 months (Fig 5 *A*), ossification has proceeded to such an extent in the lower end of the femur and upper end of the tibia that they almost cover their respective diaphyseal ends.

At this age, for the first time, one sees ossification in the upper epiphysis of the fibula and within the patella.

During the next year, the patella increases rapidly in size. It is at this time that we notice the greatest variation in the developing patella. In one instance, at 6 years and 6 months (Fig 6 *A*), the patella is about one-half inch (13 mm) in length, and in another picture (Fig 8), at 7 years and 1 month, there are two small ossifying shadows within the cartilaginous patella.

At 8 years of age, the depressions for the semilunar cartilage and the spines of the tibia are evident roentgenologically.

By the tenth year, there is a close approximation between the respective epiphyses and their diaphyses.

At 10 years and 11 months, we see the first evidence of the tubercle of the tibia. It is represented by a downward projection from the upper epiphysis of the tibia (Fig 11)

During the twelfth year (11 years and 6 months, Fig 12 *A*), the tubercle increases rapidly in size, and projects forward, being separated by a wide space from the shaft of the tibia. Union between the tubercle and shaft proceeds from above down, and from before backward.

This process can be noted by referring to Figures 14 *B* and 15.

At 18 years, this tubercle is completely ossified and united to the shaft.

In one instance (Fig 15, 14 years and 10 months), the tubercle of the tibia seems to be ossifying through two separate centers.

At 15 years and 4 months (Fig 16), there seems to be complete ossification within the epiphyses and union of the respective epiphyses and their diaphyses.

After the eighteenth year, there seems to be complete ossification of epiphyses and diaphyses.

1211 Maison Blanche

# EIGHTEENTH REPORT OF PROGRESS IN ORTHOPEDIC SURGERY \*

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LOW, M D , MURRAY S DANFORTH, M D , LLOYD T  
BROWN, M D , AND PHILIP D WILSON, M D

BOSTON

## CONGENITAL CONDITIONS

An interesting malformation of the carpus has been reported by Eaves and Campiche<sup>1</sup> This occurred in a laboring man, aged 20 who was free from all subjective symptoms and showed objectively only a freer amount of motion than normal in the carpus The roentgenogram of the right hand revealed a total absence of the scaphoid and a poorly developed radial styloid process In the left hand the scaphoid was only half as large as the normal, and the radial styloid was absent

[ED NOTE—It is apparently possible to have a functionally adequate wrist with only a small, or, indeed, without any, scaphoid The case perhaps offers further encouragement for the removal of the whole or the smaller portion of a fractured and ununited scaphoid ]

*Congenital Synostosis of the Radius and Ulna*—Wakeley<sup>2</sup> reports eight cases, with no hereditary history He considers that the operation offers small likelihood of restoring voluntary pronation and supination The danger of injuring the posterior interosseous nerve is a very real one Moreover, the disability existing from birth has been so largely compensated that the patients are often hardly conscious of their limitation

*Congenital Dislocation of the Shoulder*—Martin<sup>3</sup> has reached the conclusion that congenital dislocation of the shoulder is an extremely rare condition, the subacromial type being the least common Kirmisson, in 1898, could find but eight reported cases, and Coudray has since reported two others Other congenital characteristics were present in these two cases of Coudray, such as a lack of complete development

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\* Owing to some delay in the mails, the German articles did not arrive in time to be included in this report Comments will be made on them in the next report

\* This Report of Progress is based on a review of 466 articles selected from 504 titles dealing with orthopedic surgery, appearing in medical literature between Oct 1 1921, and Jan 21, 1922 Only those papers which seem to represent progress have been selected for note and comment

1 Eaves and Campiche J Bone & Joint Surg 4 78 (Jan ) 1922

2 Wakeley Arch Radiol & Electroth 26 185 (Nov ) 1921

3 Martin Paris med 11 469 (Dec 10) 1921

of the joint, including the head of the humerus and the acromion in one, and an abnormal development of the entire extremity in the other

[ED NOTE—These findings are interesting as tending to disprove Turner Thomas' theory of dislocation of the shoulder as the common cause of obstetric paralysis]

*Sacralization of the Last Lumbar Vertebra*—Leri<sup>4</sup> remarks that the diagnosis of a sacralization of the fifth lumbar vertebra as a cause of obscure sciatica has become the fashion. In his study of 100 roentgenograms, more than 50 per cent showed an impingement of a transverse process on the ilium, the sacrum or both. In less than 25 per cent were the outlines in accordance with the accepted norm for the region. In only 6 or 7 per cent could the symptoms reasonably be attributed to this condition.

Lupo<sup>5</sup> reports studies of the abnormalities of the fifth lumbar vertebra in children. It is apparently no more rare in children than in adults. The sacralization is more frequently bilateral than unilateral. In the first twenty years of life, there seem to be few symptoms arising from this condition. Deformities of the pelvis, congenital dislocation of the hip, coxa valga, coxa vara, etc., are quite commonly found in association with this abnormality. Of the 110 cases studied, seventy-nine were bilateral sacralizations, and thirty-one unilateral. Twenty-nine of the unilateral cases were on the left.

Schiassi<sup>6</sup> has encountered two cases of pain due to enlarged transverse processes of the fifth lumbar vertebra. The enlarged process was so situated that a foramen was formed between the neck of the process and the top of the sacrum. When the patients were subjected to repeated strains, there were evidences of pressure on the fifth nerve root, and possibly also irritation of the fourth root as it passed over the anterior surface of the enlarged fifth transverse process. He considers resection of the process to be the rational method of relief.

Bonmiot,<sup>7</sup> in an illustrated article, describes a method of approach to the root of the transverse process of the fifth lumbar vertebra in cases in which resection of the process is to be undertaken for relief of pain believed to be due to the enlargement or sacralization of this process. The approach is as follows: (1) The patient is placed in a prone position, with a sandbag beneath the anterior superior spine, the abdominal contents being thus permitted to sag away from the loin. (2) An incision, 10 cm long, is made at the outer edge of the erector spinae, extending downward to the iliac crest, and then continued

4 Leri. Bull Soc méd d hôp de Paris 45 1228 (July 29) 1921

5 Lupo. Chir d org di movimento 5 503 (Oct) 1921

6 Schiassi. Chir d org di movimento 5 229 (June) 1921

7 Bonmiot. Lyon chir 18 445 (July-Aug) 1921

downward and mesially, following the crest to the posterior superior iliac spine (3) An incision of the lumbodorsal fascia is made and the sacrospinalis muscle is mobilized and retracted mesially The branches of the iliolumbar vessels are ligated The tips of the transverse processes are felt (4) A dissection is made along the sacrospinalis as far as its iliac attachment and then the posterior portion of the iliac crest is osteotomized from a point just lateral to the muscle attachment downward to the posterior superior spine Muscle and bone fragments are retracted mesially In the sacrovertebral angle thus exposed, the transverse process lies It may be removed by careful dissection after the iliolumbar ligament and smaller muscles attached to the process have been divided The muscle and bony flap is then returned and sutured in place

[ED NOTE—The method of approach seems precise and surgical and avoids the really great danger to nerve roots of working in the bottom of a deep hole]

*Congenital Dislocation of the Hip*—The frequency of late bony changes following the reduction of congenital dislocation of the hip is attracting the attention of other investigators besides Adams<sup>8</sup> Broca and d'Intignano<sup>9</sup> find that the chief changes before reduction occur in the head of the femur, in an anteversion of the neck, and a shallow acetabulum During the period of immobilization the socket deepens, and the head and neck are modeled by pressure into varus position Sometimes they find that the constitution of the joint is apparently perfect and it would be hard to determine without previous knowledge which hip had been dislocated Some patients with a poorly developed joint develop an arthritis

Froelich<sup>10</sup> of Nancy, in two articles, also calls attention to these late changes after reduction About 33 per cent of the cases he has studied have a normal head and neck ten years after reduction, and 75 per cent of these are stable Three of 4 per cent of the patients have an arthritis resembling a caries sicca

[ED NOTE—As we have pointed out in a previous Report of Progress, it is important that we should at least be conversant with the changes which will probably take place in a majority of the reduced and functionally satisfactory cases As it seems likely that some of these changes may be attributed to the trauma incident to reduction, the emphasis should be placed on the importance of employing the gentlest methods which will successfully accomplish the replacement]

8 Adams J Bone & Joint Surg, July, 1922

9 Broca and d'Intignano Rev d'orthop 8 353 (Sept) 1921

10 Froelich Rev d'orthop, Oct 5, 1921, p 451, Presse med Oct 1, 1921

*Congenital Equinovarus*—Fiske<sup>11</sup> reports the results of a questionnaire which he sent to surgeons of wide experience in the treatment of this condition, and to which he received sixty-six replies. The preponderance of opinion favored immediate treatment of the new-born child by manipulative, retentive, and nonoperative methods. Up to 6 months, the majority favor the same nonoperative methods without anesthesia. Ten per cent were radical in their views. There seems to be a trend away from purely manipulative toward operative methods in the second year of life in uncorrected cases, but these operative methods should be limited to tenotomies, fasciotomies, and divisions of ligaments. In the adult cases all agree that bone operations are usually necessary. Fiske considers that the most important element in successful treatment is the avoidance of all unnecessary traumatism and persistence in maintaining an over-correction. Treatment should consist of manipulation to the point of tolerance, plaster or other mechanical fixation, corrective weight-bearing, massage and exercises.

#### RICKETS AND OSTEITIS FIBROSA

*Rickets*—Findlay, Paton and Sharpe<sup>12</sup> have shown that changes in bone somewhat similar to those in rickets can be induced by feeding on a low calcium diet, but the condition is of the nature of an osteoporosis and not true rickets. The calcium content of the blood and of the other tissues, except bone is not deficient in experimental rickets in dogs. Their experiments do not support the view that true rickets is due to a deficient supply of calcium to the bone.

McCollum, Simmonds, Shipley and Park<sup>13</sup> have shown that the addition of calcium carbonate to a low calcium diet prevents the development of the rickets-like condition, and that the administration of cod liver oil not only prevents the development of rickets but brings about a healing of the condition when it is well advanced. An amount of butter fat amply sufficient to protect the animals against keratomalacia does not prevent the development of the pathologic condition of the skeleton just described, and they, therefore, argue that it must exert a very feeble influence in protecting the animals against the development of rickets-like lesions.

Brown, MacLachlan and Simpson,<sup>14</sup> from a study of seven cases, have found that cod liver oil without phosphorus produces as regularly an increase in the blood calcium and an amelioration of the

11 Fiske. J Orthop Surg 3 668 (Dec) 1921

12 Findlay, Paton and Sharpe. Quart J Med 14 352 (July) 1921

13 McCollum, Simmonds, Shipley and Park. Am J Hygiene 1 492 (July)

1921

14 Brown, MacLachlan and Simpson. Canad M A J 11 552 (Aug) 1921

symptoms in rickets and tetany as does cod liver oil with phosphorus oils. They conclude that if the fat intake is 4 mg per kilogram of body weight, fat soluble vitamin A, as contained in cod liver oil, is alone sufficient to prevent or cure rickets.

Hess and Gutman<sup>15</sup> have confirmed the observation of Park and others that the lesions of infantile rickets will disappear with a daily exposure to sunlight over a period of a month or six weeks, although the diet remains unchanged. They have found that the blood serum of infants suffering from active rickets contains a diminished amount of inorganic phosphates, which phosphate content rises with the administration of cod liver oil and also with the daily exposure to direct sunlight. These findings seem to establish a chemical as well as a clinical basis for the use of heliotherapy in rickets, and they believe them to be the first definite evidence of metabolic change in the animal body brought about by the solar rays.

Mellanby,<sup>16</sup> in a well illustrated thesis, discusses the whole subject of rickets, except the theories of its etiology. His experiments were carried out in a large series of puppies. He considers that the preventive factors are (1) plenty of calcium and phosphorus in the diet, (2) certain fats identical with fat soluble vitamin, (3) meat, and (4) exercise. The diet conducive to the development of rickets he considers to consist of (1) an excess of bread, cereals and carbohydrate, and (2) an excess of protein, mostly of caseinogen, free from calcium.

*Osteitis Fibrosa*—Painter,<sup>17</sup> reporting a case in which characteristic lesions of this disease developed in two locations at widely separated intervals of time, discusses the theories of etiology. In his case there was no determinable etiologic factor. The author considers the theories of a low-grade inflammation or of an endogenous metaplasia to possess most supportive evidence. Free exposure of the lesion and curettage to solid bone effected a cure in his case.

#### TUBERCULOSIS

*Tuberculosis of the Metatarsals*—Sorrel and Bouquier<sup>18</sup> direct attention to the very frequent involvement of the first metatarsal in children. Kirmisson and Whitman have found this bone to be involved in more than 50 per cent of all metatarsal tuberculosis. The experience of the authors at Berck confirms these findings in eighteen out of thirty cases. If the head and base are uninvolved, the head should

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15 Hess, A. F., and Gutman, M. B. Cure of Infantile Rickets by Sunlight, J. A. M. A. **78** 29 (Jan 7) 1922.

16 Mellanby. Medical Research Council, Special Report Series No. 61, London, His Majesty's Stationery Office, 1921.

17 Painter. Boston M. & S. J. **185** 677 (Dec 8) 1921.

18 Sorrel and Bouquier. Paris med. **11** 399 (Nov.) 1921.



be preserved as a weight-bearing pillar, but if the head is involved, it should be removed and the great toe should always be amputated with it. Their results of this procedure they consider satisfactory.

*Tuberculosis of the Ankle in Adults*—Gaenslen and Schneider<sup>19</sup> consider the prognosis of tuberculosis of the ankle in adults to be very poor from conservative treatment. If conservative treatment is successful, they estimate the necessary period to be four years. A six months' trial of conservative treatment may be expected to determine the efficacy of this form of treatment. In cases in which operation is performed early, they expect the patient to be able to return to work in from one to two years. Amputation, and even death, results far too often from a too long persistence in conservative treatment. In their series, no case of tibio-astragaloid disease was treated conservatively.

Calvé<sup>20</sup> also believes that tuberculosis of the ankle in adults demands the same surgical attack as tuberculosis of the knee, and agrees with Gaenslen that the success or failure of conservative treatment may be determined after six months' trial, and if successful must be continued for four years.

*Tuberculosis of the Knee in Children*—Vignard and Comte<sup>21</sup> have become convinced that the operative procedure which they describe yields better results in tuberculosis of the knee joint in children than conservative treatment. They proceed on the assumption that the focus of disease is primary in the bone and invades the synovial membrane only secondarily. Their method of attack is to scrape out the tuberculous tissue in the epiphysis, leaving merely a shell, which they fill under tension with Mosetig-Moorhof paste, using special metal tubes with a piston to force in the wax after the epiphysis has been curetted. Fourteen cases in which this operation has been performed since 1919 seem to confirm them in the opinion of the advantages of this procedure. Five at this time show almost normal motion and six seem entirely quiescent with stiff joints.

Vignard and Vincent,<sup>22</sup> writing on the subject of tuberculous knees ankylosed in flexion, advocate osteoclisis rather than supracondylar osteotomy for the correction of the deformity. They say that after three years of clinical cure this procedure may be employed without danger of lighting up the disease and possesses the advantage of not shortening the limb. It does not matter whether the ankylosis is bony or fibrous. The bone is fractured usually within the capsule at the most prominent portion of the curvature.

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19 Gaenslen, F. J., and Schneider, C. C. Treatment of Tuberculosis of Ankle in the Adult, *J. A. M. A.* **77** 1168 (Oct. 8) 1921.

20 Calvé, J. *Bone & Joint Surg.* **4** 33 (Jan.) 1922.

21 Vignard and Comte. *Arch. franco-belges de chir.*, October, 1921.

22 Vignard and Vincent. *Rev. de chir.* **59** 153, 1921.

[ED NOTE—Although the Editors have had no personal experience with this method, it seems to them to involve a trauma not necessary in a linear osteotomy. The method seems unsurgical and, at least, on theoretical grounds, dangerous.]

*Tuberculosis of the Hip*—Fish<sup>23</sup> in observing 175 patients admitted to the Massachusetts State Hospital School at Canton, has been surprised at the woful lack of uniformity in treatment which these patients have received. On admission to the school, they have been treated by the Bradford abduction splint (Thomas ring knee splint with abduction arm). Fish has been impressed with the success of this treatment in preventing deformities, and advocates its more general employment when the disease is active.

*Tuberculosis of the Spinal Cord*—Browning<sup>24</sup> reports a case which he states is the eightieth on record of tuberculosis of the spinal cord. At necropsy the cord was enlarged at the level of the eighth dorsal vertebra. At this level the cord was destroyed and in a semifluid condition for some distance above and below this segment. A grayish nodule, about the size of a small navy bean, was compressing the cord beneath the meninges. The tumor was firm and shelled out easily. The microscopic examination revealed tuberculous granulation tissue.

[ED NOTE—The Editors have observed a case of tuberculosis of the spine with resistant and progressive paraplegia in which a laminectomy was performed. At operation, a firm mass of tuberculous granulation tissue was adherent to the dura and compressed the cord. The removal of this mass was soon followed by an improvement in the paraplegia symptoms, which improvement has continued more than a year. These findings may suggest the wisdom of performing more frequent laminectomies in cases of Pott's paraplegia which do not yield to treatment by recumbency and hyperextension, especially if a combined cistern and lumbar puncture (method of Ayer) demonstrates a complete block.]

#### REPORT OF COMMISSION APPOINTED BY THE AMERICAN ORTHOPAEDIC ASSOCIATION TO INVESTIGATE THE END-RESULTS OF ANKYLOSING OPERATIONS ON THE SPINE FOR CURE OF TUBERCULOUS CARIES

The commission<sup>25</sup> regrets the great laxity in keeping records which their study of the cases in the different clinics revealed. They express no opinion as to the relative merits of the inlay bone graft methods

23 Fish. Surg., Gynec & Obst **34** 79 (Jan.) 1922

24 Browning. Med Rec **100** 1021 (Dec 10) 1921

25 Brackett, Baer and Rugh (Commission). J Orthop Surg **3** 507 (Oct) 1921

and the fusion operations. The conclusions of their investigation are as follows: (1) Ankylosing operations cannot be depended on to prevent increase of deformity or bone destruction, especially in children. (2) There seems to be a favorable influence on acute symptoms exerted by the operation. (3) The operations apparently had little effect on the fusion of the vertebral bodies. (4) Too little information was secured from the records of the cases observed to warrant any conclusion as to the effect of the operation on abscess formation and paralysis. Their impression from information received was that the effect of the operation was to lessen abscess formation and paraplegia. (5) The operative risk from an operation of this gravity appears to be small. (6) The mortality can be judged only from a large series. In one group of 137 cases there were sixteen deaths, 11.68 per cent. Three deaths occurred within two months of operation, six at later periods from tuberculous meningitis or pulmonary tuberculosis, and seven from intercurrent diseases. (8) They express the opinion that the operation, if it is performed, should be regarded as an incident only in the treatment of this disease, and fixation and supportive mechanical treatment should be carried out for a sufficiently long time to afford opportunity for the ultimate fusion of the vertebra.

[**ED. NOTE**—It would seem probable, from this careful review of the end-results of such cases as have been sufficiently well recorded to be of value, that successful ankylosing operations on the spine of older children and adults may be expected to exert a favorable influence on the course of the disease and perhaps lessen the tendency to abscess formation and paraplegia. In the opinion of the Commission they cannot be trusted to cure the disease or even prevent increase in the deformity unless supplemented by the older well established, external, immobilizing methods, such as recumbency and brace treatment.]

#### SYPHILIS

*Syphilitic Arthritis*—Broca<sup>26</sup> calls attention to the great frequency of failure to diagnose chronic syphilitic disease of the joints. In nineteen out of twenty cases of syphilitic disease of the knee joint, the diagnosis of tuberculosis had been made. He describes a number of typical cases, emphasizing the importance of the Bordet-Wassermann test in cases of hydrarthrosis and arthritis without effusion, especially in the knee. The lesions are commonly bilateral, indolent, and show alternating periods of improvement and aggravation, not seriously interfering with ordinary life.

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26 Broca. Presse med. 29 873 (Nov. 2) 1921

Dufour<sup>27</sup> reports his tenth case of chronic arthritis deformans in a syphilitic patient. The type is a torpid one and appropriate treatment is usually begun too late to cure completely, though it greatly benefits.

Dupont<sup>28</sup> points out the multiplicity of manifestations in syphilitic joint disease and the intermittence of symptoms. He believes that trauma often initiates a syphilitic process in a joint, and in nearly all the cases which he has encountered a diagnosis of traumatic or rheumatic or gonococcal or tuberculous joint had been made.

#### PARALYSIS

*The Use of Electricity*—Bordier<sup>29</sup> is convinced that it is most desirable to keep the limbs affected by poliomyelitis as warm as the unaffected members, arguing that the nutritive exchanges will thereby be rendered normal and atrophy of the bones and muscles prevented. He considers that diathermy is the best method of maintaining the temperature, the limb being wrapped in a veritable mattress of cotton or wool to prevent loss of heat by radiation. He also advises the use of rhythmic and reversed galvanism of the muscles showing complete or partial reactions of degeneration.

[ED NOTE—Bordier's point of maintaining the temperature of the affected limbs may be well taken, but the experiments of Professor McLeod (University of Toronto) with limbs of animals paralyzed by section of the nerve, for example, the sciatic, and immediately sutured should give us pause in the employment of galvanism. His work has seemed to demonstrate that the symmetrical limb in the same animal not treated by electricity recovered somewhat more quickly than its treated fellow and that it was quite possible to fatigue unfavorably a muscle cut off from its central nerve supply by too much electrical stimulation.]

*The Third Year in Infantile Paralysis*—Lovett's<sup>30</sup> careful records of 180 rather severe cases occurring in the 1916 epidemic and followed closely are of great value. The muscles of the arm, back and abdomen showed greater improvement than those of the lower limb, and their improvement was fairly continuous. The muscles of the leg often showed loss of power during the third year. The chief cause of this was the development of deformity, which occurred in spite of every care on account of the lack of muscle balance. The loss of power was evident in contracted and stretched muscles and others which did not

27 Dufour Bull Soc med d hop de Paris, July 22, 1921

28 Dupont Rev de chir 59 264, 1921

29 Bordier Arch Radiol & Electroth 26 215 (Dec) 1921

30 Lovett R W Third Year in Infantile Paralysis, J A M A 77 1941 (Dec 17) 1921

function well after stabilizing operations. Over-fatigue by walking was responsible in a few cases for a loss of power. Lovett concludes that deformity, stretching and fatigue are the chief obstacles to the successful treatment of poliomyelitis.

*Early Treatment of Infantile Paralysis Based on Physiologic Indications*—Feiss<sup>31</sup> suggests that on physiologic grounds voluntary and assisted motions of the affected limbs are indicated in the early acute stage of poliomyelitis. He has had no opportunity to test this theory in any considerable number of cases.

[Ed. Note.—It would seem to the Editors that this suggested method of treatment is contraindicated by most of our experience in the treatment of acute cases. Perhaps the method may well be held *sub judice* until its success has been demonstrated in a large number of cases.]

*End-Results of Operative Procedures*—Gill<sup>32</sup> has studied the end-results of operative procedures for the improvement of function in cases of poliomyelitis, with especial reference to the results of tendon transplantations in the cases at the Widener Framing School for Crippled Children in Philadelphia. One of the important causes of failure has been the fact that the transplantation has not been sufficient to stabilize the foot. He urges the more frequent employment of horizontal transverse section through the subastragaloid joint, with the displacement of the foot backward. He considers 7 to 8 years the favorable age for operation.

*Hoke's Stabilizing Operation*—Hoke,<sup>33</sup> frankly admitting that no one can convert a paralytic deformed foot into a normal one, considers that the results of operative procedures may be reasonably expected to bring about the following desiderata: (1) natural appearance in shoes, (2) stabilization, so that the patient will not turn laterally on the long axis of the foot when the patient is standing or walking, (3) stability in the natural or nearly natural attitude, so that they do not need braces to hold them so, (4) the presentation of no gross deformity when barefooted. Hoke considers that tendon transplantations have been largely distinguished by their failures. The fixation of tendons to bone to produce stability is, in his opinion, unmechanical in principle, and he has not attempted to attain stability by this method. Hoke bases his operations on a knowledge of the architecture of the foot, the most important structure of which he considers to be the head and neck of the astragalus. The chief feature

<sup>31</sup> Feiss, H. O. Treatment of Early Infantile Paralysis as Based on Physiologic Indications, *J. A. M. A.* **78** 85 (Jan. 14) 1922.

<sup>32</sup> Gill, J. *Orthop. Surg.* **3** 677 (Dec.) 1921.

<sup>33</sup> Hoke, J. *Orthop. Surg.* **3** 494 (Oct.) 1921.

of his operation is the removal of the head and neck of the astragalus through a curved lateral incision, reshaping it and perhaps denuding it of cartilage as the architecture to be corrected requires, and then replacing it. Judgment and experience are obviously required in reshaping this key bone in the different types of paralytic clubfoot, dropfoot, flatfoot and their combinations. The articular surface of the scaphoid and the superior surface of the os calcis are denuded of cartilage, assuring an arthrodesis. If there is much torsion of the tibia, causing rotation of the lower leg and a backward position of the external malleolus, an osteotomy of the tibia is performed in its upper third. Hoke has been able to observe the end-results of fifty-four of his 104 operations of this type, from six months to three years after the operation. In one case a second operation has been performed. All the other patients possessed stable feet when observed.

[ED NOTE—Hoke's illustrations are very impressive. Some of the Editors have seen many of his end-results and consider them most satisfactory. The flexibility and normal appearance of the feet are quite striking. His methods seem to the Editors to warrant a more extensive trial by other surgeons.]

*Operation for Valgus Feet*—Roberts<sup>34</sup> has devised an operation for selected cases of paralytic valgus. These are cases in which there is either no power or a negligible amount of power in the anterior tibial muscle and an overaction of the common extensor and the peroneals. The Achilles tendon is lengthened if necessary. An anterior incision is made from the junction of the lower and middle thirds of the leg to the annular ligament. The anterior tibial is divided at the junction of its tendon and muscle, overlapped and sutured with the foot in slight varus and dorsiflexion. The common extensor tendon is divided at the annular ligament, the distal end left free, and the proximal passed through two slits, being woven into the anterior tibial tendon, and sutured thereto. He reports forty cases with satisfactory results and frequent return of power of the anterior tibial muscle.

Mayer<sup>35</sup> has divided paralytic flatfeet into four types. (1) impairment but not total loss of power of the tibialis anticus. Treatment consists in correction of the deformity and treatment by brace and exercise. (2) Tibialis anticus completely paralyzed and weakness of the other invertors. Treatment consists in mild cases of transplanting the extensor longus hallucis to the dorsum of the foot, in more severe cases the peroneus longus being brought forward to replace the tibialis anticus. (3) Tibialis anticus and tibialis posticus both paralyzed.

34 Roberts P W. Operation for Valgus Feet J A M A 77 1571 (Nov 12) 1921

35 Mayer J Bone & Joint Surg 4 39 (Jan) 1922

Mayer believes that no treatment by means of transplantation of tendons alone is satisfactory, including the Whitman loop operation (4) All invertors of the foot, including the gastrocnemius, paralyzed After a bone stabilization of the ankle, Mayer divides, but does not transplant, the tendons of the peroneals and toe flexors

[ED NOTE —It has seemed to us that in this fourth type, after an astragalectomy or subastragaloid stabilization, the tendons of the peroneals may be safely transplanted into the os calcis, being no longer needed for lateral support]

#### ARTHRITIS

*Maximum Fat Feeding in Arthritis*—Wright and Hubbard<sup>36</sup> advocate a 70 to 75 per cent fat diet in cases of chronic arthritis They have found only slight traces of acetone bodies in the excreta Response to this diet must be carefully checked by urinalysis, but in this way, diets containing minimal amounts of carbohydrates may be administered while the body weight is maintained

*Acute Condition of Joints*—Ober,<sup>37</sup> after a long war experience, advises against a too quick abandonment of immobilization in septic knee joints By no means all septic joints treated by a bent Thomas splint and with careful attention to minor detail become stiff Surgical interference must be gentle and precise Passive manipulation, frequent irrigations, and too frequent changing of the dressing all tend, in Ober's opinion, to prolong the septic process

Some interesting facts and figures have been brought out by Collings'<sup>38</sup> study of 517 cases of gonococcal arthritis in the Bellevue Hospital wards If a patient has once suffered from a gonorrheal arthritis and receives a reinfection, a return of the gonorrheal arthritis may be expected Seventy-five per cent of the cases of gonorrheal arthritis develop within fifteen days of the urethral infection The infection is usually multiple Trauma and preexisting chronic arthritis predispose Collings has been dissatisfied with the relief afforded by vaccines, serums, drugs and operations on the seminal vesicles In a recent series of twenty-six cases, in addition to removal of obvious pyogenic foci and general measures, heavy plaster casts were applied and the patient anchored in bed by them These casts have been split after two weeks, the joints exercised, and the cast reapplied for two weeks more, followed by baking, massage and exercises If this treatment is started early, excellent results may be expected None of these

36 Wright and Hubbard New York State J Med **21** 403 (Nov) 1921

37 Ober J Orthop Surg **3** 689 (Dec) 1921

38 Collings, C W Cast Treatment of Gonorrheal Arthritis, J A M A **77** 1789 (Dec 3) 1921

joints became ankylosed or required arthrotomy. The relief has been permanent in seventeen of the cases followed. Of his 517 patients treated by other methods, 290 were discharged improved, sixty were considered cured, five by operation, thirty-seven were unimproved, and 100 were sent to other hospitals or left the hospital at their own risk.

Ballenger and Elder<sup>39</sup> have been treating gonococcal arthritis for several years by withdrawing, by aspiration, fluid from affected joints and injecting from 15 to 50 c c, intramuscularly, from every two to seven days. In acute cases, they report prompt improvement and remarkable cures. They state they have abandoned other methods or treatment, such as serums, local applications and fixation. There has been accompanying improvement in other complicating conditions, such as epidymitis, prostatitis, posterior urethritis and seminal vesiculitis. Excellent results in twenty-seven cases are detailed. They consider this a preliminary report and reserve their discussion for a later communication. They also state that in sixteen cases of traumatic arthritis in which they employed the same method, these cases made more rapid recoveries than in a control series in which the joint fluid was simply aspirated, but not injected.

Dufour, Thiers and Alexewsky<sup>40</sup> reported, a year ago, six cases of purulent arthritis rapidly and completely cured by three aspirations and injections of 0.6 c c of the aspiration material, subcutaneously. One patient recovered in four days after a single injection of 20 c c.

Sieur<sup>41</sup> has observed the results obtained in blennorrhagic arthritis by the injection of a serum prepared by himself. The injections are given daily for four days. The first day 0.5 c c is given, the second day, 1 c c, the third, 1.5 c c, and the fourth, 2 c c. Joint motion was preserved.

[ED. NOTE.—The Editors have had no experience with this method of treating purulent arthritis. No explanation is offered by the authors, but coming from widely different sources, the reports merit attention and perhaps a trial of the method.]

*Coxa Plana (Legg-Calve-Perthes Disease)*—Calve<sup>42</sup> deduces certain conclusions as to the etiology of osteochondritis of the hip joint in children, or coxa plana, as he prefers to call it, from a case in which roentgenograms were available more than a year before the onset of symptoms. The case was followed by roentgenograms, taken two and one-half years after the onset of symptoms. The conclusions are (1) The affection is not congenital. (2) The phase of invasion of the

39 Ballenger and Elder. Surg, Gynec & Obst **33** 574 (Nov.) 1921.

40 Dufour, Thiers and Alexewsky. Paris med **11** 472 (Dec.) 1921.

41 Sieur. Paris med **11** 340 (Oct. 29) 1921.

42 Calve. J. Orthop. Surg **3** 489 (Oct.) 1921.



epiphyseal nucleus is latent from the clinical point of view (3) The clinical phase, corresponding to the period when the child first begins to complain of pain is considerably later than the real beginning of the trouble (4) At the beginning of the clinical phase, there is a corresponding roentgenogram showing an established and characteristic lesion, namely a laminated and fragmented epiphysis (5) The regeneration of the osseous epiphyseal nucleus occurs progressively as the osseous fragments augment in volume, and reunite finally forming one single mass This regeneration continues, and there is a tendency to a return of normal form Calvé believes that the condition represents an acquired articular malformation, characterized by a flattening of the upper femoral epiphysis

Murk Jansen,<sup>43</sup> on the other hand, believes the etiology of coxa plana may be explained by the laws of bone growth, formation and deformation He considers the condition congenital, developing only after some years of walking He has noticed that the widening of the femoral neck precedes the characteristic flattening and cleavage of the epiphyseal bone center He has noticed also that coxa plana often develops a short time after infectious diseases, the injurious agents of which have, in his opinion, temporarily enfeebled the power of growth of the bone and contributed to its plasticity The association with congenital dislocation of the hip is mentioned and the condition often follows reduction The signs of local infection Jansen considers to be absent

Mouchet<sup>44</sup> also regards the condition as a disturbance of growth

Vulliet<sup>45</sup> applies the name dystrophia to this condition and places it in the same class as lesions of the tibial tubercle, scaphoiditis, and apophysitis He notes its indolence and its spontaneous functional recovery

*Hypertrophic or Degenerative Arthritis or Osteo-Arthritis*—Ely<sup>46</sup> calls this form of arthritis the second great type The essential pathology, in his opinion, is an aseptic necrosis in the bone marrow near the joint surface He assumes infection to have been originally present, but to have died out The dense eburnated bone is the wall nature builds up between the diseased area and the joint, and the cartilage degenerates and wears off The condition is more frequent in men than in women and is a disease of later life Ely has found an almost constant association of infection in the alveolar processes and believes that the first step in treatment should be the removal of all dental foci of infection

43 Jansen J Orthop Surg 3 706 (Dec) 1921

44 Mouchet Medecine 3 27 (Oct) 1921

45 Vulliet Rev med de la Suisse Rom 40 806 (July) 1921

46 Ely California State J M 19 415 (Oct) 1921

A later report of Ely, Reed and Wyckoff<sup>47</sup> announces the discovery of an ameba in the cavities which he has described in a freshly removed head of the femur. The presence of this ameba has been confirmed by Kofoed, and experiments are in progress to determine whether satisfactory proof can be established which will connect this ameba with the disease in an etiologic relation.

At a recent meeting of the British Orthopaedic Association,<sup>48</sup> an important and lengthy discussion was held on the operative treatment of osteo-arthritis of the hip. The views expressed were varied, but no surgeon present was inclined to be dogmatic concerning either operative treatment in general or any special operative procedure. It was generally agreed that the degenerated, overgrown, often mushroomed head of the femur, seen so often as a result of the chronic arthritis of later life, presented the most serious problem of treatment. Elmslie believes that in this type arthrodesis is a better operative procedure than excision. Sir Robert Jones also cautioned against excision in the older cases, considering it accompanied by too much shock. Aitken, in closing the discussion, stated that it seemed to be the consensus of opinion of those present that if motion was the end sought by operation, a free excision was more likely to afford a satisfactory end-result in these cases than was a more formal arthroplastic operation.

#### NEOPLASMS

*Sarcoma of Bone*—Greenough, Simmons and Harmer<sup>49</sup> have reviewed the 148 cases of patients with what was supposed to be bone sarcoma admitted to the Massachusetts and the Huntington Memorial hospitals for a period of ten years. Adopting Ewing's classification, they found twenty-seven cases of the osteogenic type, twelve cases of benign giant cell tumor, one case of angiosarcoma, three cases of myeloma, in which full and conclusive data were available. A history of trauma was more frequently obtained in the osteogenic type than in the other types, ten out of twenty-seven. Spontaneous fracture was common.

The roentgenograms are quite characteristic in the ordinary periosteal variety of osteogenic tumor, with its new periosteal bone and raylike appearance, but five of their osteogenic cases showed the tumor to be of central origin, with no obvious new growth beyond the cortex, and very like, in roentgenologic appearance, a giant cell tumor. In two of their cases, there was little evidence of new bone formation and some evidence of bone destruction, resembling very closely a

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47 Ely, Reed and Wyckoff. California State J. M. 20:59 (Feb.) 1922.

48 British Orthopaedic Association. J. Bone & Joint Surg. 4:137 (Jan.) 1922.

49 Greenough, Simmons and Harmer. J. Orthop. Surg. 3:602 (Nov.) 1921.

metastatic cancer or an osteomyelitis. The characteristic cell of the fundamental tissue is the spindle cell fibroblast, the progenitor of bone forming tissue. They report three (since publishing only two) apparent cures without known recurrence from twenty-three amputations or radical removal in osteogenic sarcoma. One of these was of the jaw. The average duration of life in patients dying of recurrence was 11.5 months. They have observed no material benefit from treatment by Coley's serum in four cases. They agree with Bloodgood as to the benign nature of this condition, with no tendency to metastasis. The tissue is composed of fairly typical fibroblasts and large numbers of endothelial foreign body giant cells, which dominate the picture. New bone production is not characteristic. Thorough local extirpation is advised. In the three cases of myeloma proved by microscopic examination the picture was of plasma cell myeloma. Two were apparent instances of single foci of the disease. No Bence-Jones bodies were ever demonstrated in the urine of these patients.

Harmer,<sup>50</sup> writing independently on bone sarcoma, urges the cooperation of all surgeons with the Registry of Bone Sarcoma, which has been established by the American College of Surgeons under Codman, Bloodgood and Ewing. Information may be obtained from Dr E. A. Codman, 227 Beacon Street, Boston, Mass.

Barrie<sup>51</sup> still maintains that the so-called giant-cell benign tumors have few, if any, characteristics which entitle them to be classed as sarcomas. Seventy-five per cent of Barrie's forty cases suggest trauma as the etiologic factor. In no case in which ossification had not occurred, that is, in the youthful cases, had there been a penetration of the epiphyseal cartilage. He urges that these lesions be classed as osteomyelitis, and uses the term hemorrhagic osteomyelitis.

Turner<sup>52</sup> reports two cases of myeloma of the vertebrae which came to necropsy. The course in one had been progressive, with severe pain, emaciation, moderate cachexia, diarrhea and coma, in the other, there had been paraplegia, cystitis and death. The roentgenograms had shown extreme atrophy of the bodies, with narrowing and flattening, but no disturbance of the intervertebral disks.

Morrison<sup>53</sup> records an apparent cure by roentgen-ray therapy of a case of osteosarcoma of the femur with metastasis. A section for microscopic examination had been removed from the femur, but no attempt had been made to eradicate the disease. Later there was a fracture of the femur. There were metastases in the left frontal and

50 Harmer. *Boston M & S J* **185** 446 (Oct 13) 1921

51 Barrie. *J Bone & Joint Surg* **4** 164 (Jan) 1922

52 Turner. *J Orthop Surg* **3** 698 (Dec) 1921

53 Morrison. *Am J Roentgenol* **8** 565 (Oct) 1921

right occipital regions. The frontal lesion was incised and drained and yielded more quickly to the same dosage of radiation than the occipital lesion.

#### OSTEOMYELITIS

*Osteomyelitis Secondary to Compound Fracture*—Mebane<sup>54</sup> has analyzed 359 cases of chronic osteomyelitis secondary to compound fracture encountered at Fort Sheridan from August, 1919, to August, 1920. More than half of these required further operative work, 143 bone operations, fifty-six plastic operations, and thirty-six drainage operations for abscess. About 10 per cent were still unhealed after two years of hospital treatment. In this series, chronic osteomyelitis of spongy bone, that is, of the epiphyseal portions of the long bones and of the carpal and tarsal bones, was more difficult to cure than osteomyelitis of the compact shaft of the long bones. His conclusion is that in extensive tarsal involvement, if healing has not taken place in six months of efficient treatment, amputation is to be advised, and he holds the same view in relation to epiphyseal osteomyelitis when resection is impracticable. Osteomyelitis of the femur seems the most difficult to cure. Forty-five per cent of the unhealed cases involved this bone. The operative measures which gave the best results were careful effacements and partial closures. Thorough surgical procedures are more important than the employment of chemicals at the time of operation. Refracture is a common sequel, but union is the rule. Nonunion occurred in only two of the fourteen cases of refracture.

*Unusual Bone Involvements*—Duguet<sup>55</sup> reports a case of osteomyelitis confined to the patella. The joint was aspirated and a negative culture obtained. Two fistulas occurred and later a sequestrum was removed from the patella without signs of infection of the joint. There was some separation of the cartilage from the bone, and excellent function resulted with a normal gait. Little bone regeneration occurred and atrophy of the quadriceps persisted.

Valentini<sup>56</sup> reports a case of osteomyelitis (mixed *Staphylococcus aureus* and streptococcus, involving the fibula only). He can find only four other cases reported in the literature. Two large sequestrums were removed, the cavity of the bone curetted, and prompt healing took place.

Geist<sup>57</sup> has encountered six cases of osteomyelitis of the pelvic bones, five of them in children. In only one case was the hip joint

54 Mebane. J Bone & Joint Surg. **4** 67-77 (Jan.) 1922.

55 Duguet. Paris med. **11** 474 (Dec.) 1921.

56 Valentini. Riforma med. **37** 946 (Oct.) 1921.

57 Geist, E. S. Osteomyelitis of Pelvic Bones, J. A. M. A. **77** 1939 (Dec 17) 1921.

involved later. Three cases involved the ilium, two the ischium and one the pubes. All the patients recovered after surgical interference, with persisting sinuses in only two cases. In all the cases, there were an acute onset, fever and pain referred chiefly to the hip and leg.

Jones<sup>58</sup> reports a typical case of the sclerosing, nonsuppurative osteomyelitis described by Garre in 1891. He considers the condition a distinct entity. In most cases the onset is acute, accompanied by fever, swelling of the affected limb, pain at the site of the bone lesion, and infiltration of the soft parts, without reddening of the skin. At operation no pus is found and the process is chiefly a proliferative one, the medulla being converted into a sclerosed mass of bone. The cultures were negative and the microscopic examination revealed only sclerosis. Pain was relieved by opening the sclerosed mass into what was formerly the medulla. Convalescence was uneventful. The condition may well be confused with syphilis, the solid types of osteitis fibrosa and sarcoma. Jones hazards the opinion that some of the cases of osteogenic sarcoma reported as cured by amputation represent this condition wrongly diagnosed.

#### SURGERY OF BONES, JOINTS AND TENDONS

*Bone Transplantation*—Nathan<sup>59</sup> discusses the biology of bone development. He affirms the original conclusions of Ollier and considers the diversities of opinion which have since arisen to be due not to differences in actual experimental findings, but simply to a confusion of terms. Nathan is convinced that bone dies when transplanted, whether supplied with periosteum or endosteum, neither or both. Bone is produced only by those cells called osteoblasts. These cells are confined to the cambium layer of the periosteum or endosteum and are found to some extent in the bone marrow. When the transplant consists of bone denuded of both periosteum and endosteum, osteoblasts can come only from the living bone into which it is implanted. On the other hand, the grafts which contain these structures are already supplied with osteoblasts and these cells are excited to proliferation when in contact with dead bone. Thus, the regenerative process is greatly increased in rapidity and extent, and the chances of development of new bone before the transplanted bone is completely absorbed are greatly enhanced.

McWilliams<sup>60</sup> study of 1,390 cases of bone grafting reports 82.3 per cent of success and 17.6 per cent of failures. The percentage of

58 Jones, S. F. Sclerosing Nonsuppurative Osteomyelitis as Described by Garre, J. A. M. A. **77** 986 (Sept. 24) 1921.

59 Nathan. New York M. J. **114** 454 (Oct. 19) 1921.

60 McWilliams. Ann. Surg. **74** 286 (Sept.) 1921.

successes by different methods was as follows (a) simple bone pegs, 95.8 per cent, (b) osteoperiosteal method (Delangeniere) 87.3 per cent, (c) end-to-end without inlaying, 82.5 per cent, (d) inlay method, 80.9 per cent, (e) intermedullary method (Murphy), 76.6 per cent, (f) combined intermedullary at one end and inlay at the other, 60 per cent. The statistics seem to show that the presence or absence of the periosteum of the graft makes no difference in the likelihood of success. Thirty-two per cent of the infected cases were successful, but suppuration is the commonest cause of failure. Failure to immobilize sufficiently thoroughly, and for a period of from four to six months appeared to be a second common cause of failure. The most successful method seems to be the osteoperiosteal method of Delangeniere, the defect being filled in with bone chips, and one or two strips of periosteum with adherent osseous plaques taken from another bone being laid in, covering the bone chips and overlapping the ends of the fragments. The method is applicable to both large and small defects. The intramedullary method of grafting should be discarded, in McWilliams' opinion. There would seem to be sufficient evidence to prove that the most effectual treatment of nonunion of fractures is bone grafting.

Fieschi<sup>61</sup> reports a case of removal of the entire ulna, except its upper epiphysis, for tumor, and the substitution of a similar portion of the ulna from a cadaver, sterilized in an autoclave. The wound healed by first intention, but in spite of this fact and the mechanical need of substitution, the host never ceased to attack the foreign body, and in forty-two months roentgenograms revealed complete absorption.

*Tendon Transference*—Starr's<sup>62</sup> conclusions from a study of the end-results of fifty-two operations of tendon transference which he has performed for the relief of war injuries, chiefly in irreparable nerve injuries in the arm, are valuable. (1) So far as possible, muscles having similar action to the ones they are to replace should be employed. (2) If only a portion of a muscle is to be employed, it must have the same action as the muscle it is to replace. (3) The line of pull should be as straight as possible. (4) The fixation of the muscle should be made with a good deal of tension. (5) Bony deformity due to contraction of tissues should be overcome before the transfer of muscles is attempted. (6) Tendons should run in fatty subcutaneous tissue rather than in the sheath of other muscles. (7) In the lower extremity transferred tendons should be inserted into bone or periosteum. In the upper extremity, they may safely be attached to paralyzed tendons.

61 Fieschi. *Chir. d. org. d. movimento* 5:359 (Aug.) 1921.

62 Starr. *J. Bone & Joint Surg.* 4:3 (Jan.) 1922.

(8) Linen thread is the best material for suture, and the fixation of tendon to tendon must be adequate (9) Immobilization for three weeks should be the rule and then muscle training begun

Henderson<sup>63</sup> has employed the tendon of the peroneus longus to make good a defect in the triceps tendon, interlaying it into the triceps muscle and inserting it into the proximal end of the ulna. He finds the results quite satisfactory and the peroneus brevis and tertius have been strong enough to preserve the stability of the foot.

*Central Bone Abscess*—McWilliams<sup>64</sup> quotes Brodie's original article to prove that the condition he described (Brodie's abscess) was not a tuberculous abscess as he supposed, but a pyogenic one. Of 115 cases of chronic suppurative osteomyelitis treated at the Presbyterian Hospital in seven years, only three represented true Brodie's abscess. They are treated successfully by opening, cleaning them out, partially closing them, and treating them by surgical solution of chlorinated soda (Carrel-Dakin technic) until the smears show no organism when they are closed by secondary suture. He calls attention to the fact that the roentgenograms may fail to show any more centrally located lesion because the surrounding bone is sclerosed, and he advocates exploring any tender swelling of bone in which traumatic periostitis, syphilis, cyst and neoplasm can be ruled out.

*Spiral Fracture Tubercle of Tibia (Osgood-Schlatter)*—Solieri<sup>65</sup> and Soule<sup>66</sup> both report successful treatment of these partial detachments or traumatic epiphysites of the tibial tubercle by driving a bone peg through the affected tubercle into the tibia.

[ED. NOTE—We have no doubt of the success of this measure, but we have yet to see a typical case in which a quick and permanent relief from symptoms cannot be attained by adhesive plaster strapping maintained for five or six weeks, the patient being allowed to be about on his leg. We do not consider a true separation of the tubercle in an adult a typical case of this syndrome. Bone pegs and more complete fixation may well be advisable in these more severe injuries, but in the ordinary adolescent case we may perhaps choose the less elaborate and less laborious of two equally successful methods of therapy.]

*Shoulder and Arm Disabilities*—Steindler<sup>67</sup> has again studied the end-results of his operative procedures for shoulder and arm disabilities. He is gratified at the results in his cases of arthrodesis of the shoulder, which he believes may be successfully accomplished as

63 Henderson M. S. Restoration of Triceps Tendon by Transplantation of Peroneus Longus. *J. A. M. A.* **77** 1572 (Nov. 12) 1921.

64 McWilliams. *Ann. Surg.* **74** 568 (Nov.) 1921.

65 Solieri. *Chir. d. org. d. movimento* **5** 353 (June) 1921.

66 Soule. *J. Orthop. Surg.* **3** 550 (Oct.) 1921.

67 Steindler. *J. Orthop. Surg.* **3** 652 (Dec.) 1921.

early as 6 years of age, by making a curved incision from the spine of the scapula to the coracoid process, dividing the acromion and reflecting it with the deltoid muscle, which gives an excellent approach to the joint. He recommends fixation at a right angle to the body in the neutral position in children. Steindler is also continuing to perform his operation of transplanting the whole origin of the flexor group of muscles in certain cases of arm paralysis to a point 2 inches (5 cm) higher up, holding the arm in acute flexion for two months and beginning massage and exercise in the third week. The best results were obtained when the operation was combined with arthrodesis of the shoulder or wrist.

*Posterolateral Incision for Removal of Loose Bodies from Posterior Compartment of Knee Joint*—Henderson,<sup>68</sup> finding the straight, posterior, median incision of Brackett and Osgood difficult to make in fat patients and requiring careful dissection to avoid injury to the vessels and nerves, has approached this deeply placed compartment of the knee by lateral incision. The patient lies on his back and the knee is flexed. For a mesial approach, the incision is just in front of the relaxed tendons of the sartorius, gracilis, semitendinosus and membranous muscles. For a lateral approach, the incision is in front of the line of the fibula.

[ED. NOTE—We still consider that the median posterior incision affords, except perhaps in very fat patients, a more complete exposure to all parts of the posterior compartment of the knee joint. The danger of wounding the vessels and nerves is hardly to be feared. These structures may be easily, without undue trauma, retracted to the outer side.]

*Reconstruction of the Lateral Ligament of the Knee Joint*—Wilson,<sup>69</sup> in a well illustrated article, describes the details of an operation which he has performed successfully in two cases of torn internal lateral ligament of the knee. This consists in turning down a wide flap of fascia lata, three times as broad as is required, and after having folded it on itself, inserting it into the bone of the femoral condyle and tuberosity of the tibia by raising osteoperiosteal flaps and suturing them over the insertion of the fascia. Wilson states that persistent abnormal abduction of the leg in extension, without abnormal anteroposterior or lateral mobility in flexion, is probably due to laceration of the internal lateral ligament. Persistent instability due to laceration of the internal lateral ligament will require correction by surgical procedure.

68 Henderson Surg Gynec & Obst 33 698 (Dec) 1921

69 Wilson J Bone & Joint Surg 4 129-134 (Jan) 1922



*Special Knife for Removal of Meniscus of Knee*—Freiberg<sup>70</sup> has devised a special knife to facilitate the removal of the posterior portion of a meniscus of the knee joint. The knife has a cutting edge at an angle of 135 degrees with the shank, its end being rounded instead of pointed, so that one may cut with the extreme end of the knife as well as with the blade. The shank of the knife is 2 inches (5 cm) long and the handle is 5 inches (12.7 cm).

#### PERIPHERAL NERVE LESIONS

Platt,<sup>71</sup> after a very wide experience in the surgery of peripheral nerve lesions advocates (1) the most ample anatomic exposure from the beginning of the operation, as a routine, (2) the constant employment of direct electrical stimulation by means of the bipolar electrode, (3) the standardization of those positions of the patient and the limb on the operating table which will minimize the difficulties of accomplishing end-to-end suture without undue tension. Platt has followed the end-results of 248 cases. One hundred and fifty of these were end-to-end sutures. Seventy-nine per cent presented varying degrees of recovery, 21 per cent were complete failures. The influences which inhibit the success of the operative procedure are (1) the period since injury, progressively inferior results being seen with increasing delay, (2) infection, which delays regeneration, (3) the nature of the nerve bed, which is almost negligible unless the nerve trunk is subjected to bony friction, (4) the topography of the nerve, accounting for many failures, (5) level of suture, regeneration in the distal part of the limb being likely to be fickle. Eighty operations of neurolysis were performed, with 75 per cent of recoveries or improvements, but Platt believes that it is difficult to estimate the exact influence of the operation. Eighteen operations of nerve bridging were performed and they were all complete failures.

MacKay,<sup>72</sup> from a study of more than 600 nerve cases at the Cranville Canadian Hospital, has become convinced that the analysis of the voluntary muscular control is the surest guide to the determination of the exact nerve lesion. Trick movements must be most carefully excluded.

Harris<sup>73</sup> has written a valuable article on the treatment of irreparable nerve injuries, dealing with the detailed anatomy of the forearm and hand. The article cannot well be reviewed in short space but should be commended.

70 Freiberg J Orthop Surg **3** 697 (Dec) 1921

71 Platt J Orthop Surg **3** 569 (Nov) 1921

72 MacKay Surg, Gynec & Obst **33** 646 (Dec) 1921

73 Harris Canad M A J **11** 833 (Nov) 1921

*Writers' Cramp*—Bates<sup>74</sup> reports three cases of so-called writers cramp which he relieved completely by the simple method of having the patients note the position in which they placed their hands during sleep. It was found that all three slept with their hand or hands (in the bilateral cases) beneath the cheek or head. The symptoms entirely disappeared when the habit was corrected.

#### DISLOCATIONS

*Carpal Luxations and Subluxations*—Nicotra<sup>75</sup> discusses the dislocations of the carpal bones and reports two cases of crushing, twisting injuries, causing fracture luxations and subluxations of the scaphoid, semilunar and cuneiform bones. An interesting observation of the author is that fractures of the scaphoid are usually due to falling on the palm with the hand dorsally flexed on the forearm and radially deflected, while dislocations are due to falling on the palm, with the hand dorsally flexed on the forearm, but deflected ulnaward.

*Subluxation of the Shoulder Downward*—Cotton<sup>76</sup> calls attention to a group of shoulder injuries followed by a troublesome weakness of the deltoid and supraspinatus, which are often diagnosed as circumflex paralysis. These symptoms are due, he thinks, to a sagging of the heavy, swollen arm, often suspended in fractures of the humerus only by the wrist, which results in a true subluxation of the head downward in the glenoid and an overstretching of the deltoid and supraspinatus. The treatment consists of early massage and the support of the whole arm as soon as the condition of the lesion makes it possible. He reports nine cases.

*Recurrent Dislocation of the Shoulder*—Sandes<sup>77</sup> fashions an artificial ligament from a strip of fascia lata, and passing it through a drill hole in the head of the humerus, fastens it as a sling over the clavicle.

Tavernier and Jalifer<sup>78</sup> recommend a very thorough examination of patients exhibiting this condition and urge a more complete operation than simple capsulorrhaphy. The capsule should be opened and the joint examined. In one of their cases a diverticulum in the antero-mesial portion of the capsule was discovered and, in another a tear of the capsule was found in the antero-inferior quadrant, with detached ends hanging loosely into the joint.

74 Bates. *Med Rec* 100 415 (Sept 3) 1921

75 Nicotra. *Chir d org d movimento* 5 243 (April) 1921

76 Cotton. *Boston M & S J* 185 405 (Oct 6) 1921

77 Sandes. *Brit M J* 2 321 (Aug 27) 1921

78 Tavernier and Jalifer. *Rev d'orthop* 1921 No 4 p 275

*Congenital Dislocation of the Shoulder* —Taylor<sup>79</sup> replies to the article of T T Thomas, in which Thomas maintains that the cause of brachial palsy is a congenital dislocation or posterior subluxation of the shoulder. Taylor has been unable to find a record of a single case of posterior subluxation of the shoulder noted at birth in association with brachial palsy or obstetric paralysis. Obstetricians connected with three large lying-in hospitals in New York have never seen the association of the two conditions at birth. Taylor has never seen a posterior subluxation of the shoulder in a case of brachial palsy in a patient less than 6 weeks old. He concludes that the subluxation must be secondary and not primary, and presents many cases in which positive findings in injury to the roots of the brachial plexus have been demonstrated at necropsy.

*Luxation of the Right Iliac Bone* —Montagard and Moreau<sup>80</sup> have seen a case in which, as the result of an automobile accident, the right iliac bone, as a whole, had been dislocated upward, both at the symphysis pubis and the sacro-iliac synchondrosis. The lower border of the right acetabulum was on a level with the upper border of the left. There were no signs of fracture to be discovered. Partial calcification of the fibrocartilage between the separated bones had taken place and some osteophytic change. The patient walked well, with no inconvenience, except for the shortening.

#### FRACTURES

*Fractures at the Wrist* —Schurmeier<sup>81</sup> has noted the much higher percentage of articular involvement in chauffeur's fracture of the radius than in the ordinary Colles' fracture. He explains this fact by the different direction in which the causative force is applied. In Colles' fracture the force is applied with the wrist dorsiflexed and radially deflected (abducted), and the articular surface of the radius comes in contact with the broad surface of the scaphoid and usually escapes injury. In chauffeur's fracture, the force is received with the wrist in the neutral position and deflected ulnaward (adducted), which brings the articular surface of the radius in contact with the angular or pointed surface of the scaphoid, which frequently causes splintering of the articular surface.

*Supracondylar Humeral Fractures* —Baumgartner<sup>82</sup> reports practically perfect results in five cases of supracondylar fracture of the

79 Taylor. *Ann Surg* **74** 368 (Sept.) 1921

80 Montagard and Moreau. *Rev d'orthop*, September, 1921, p. 414

81 Schurmeier, H. S. Traction Device for Use with Thomas Splint, *J. A. M. A.* **76** 2119 (Dec. 31) 1921

82 Baumgartner. *Rev. med. de la Suisse Rom.* **40** 816 (April) 1921

humerus treated by continuous traction and counter traction with the arm in a straight line. In the early cases the traction satisfactorily reduced the deformity. In two older cases it maintained the position after manipulation had reduced the deformity.

*Fracture of the Neck of the Scapula*—Cotton and Brickley<sup>83</sup> do not agree with Sir Astley Cooper's classical picture in fracture of the neck of the scapula of a drooping shoulder replaceable, but tending to fall away from gravity pull. As they have seen the condition, the shoulder appears to be displaced inward and to be narrower than the normal side. Their treatment is to reduce the deformity by levering the head of the humerus outward, over the fist, in the axilla as a fulcrum. A heavy wedge-shaped pad is placed in the axilla, the arm is brought to the side and held as tightly as the circulation will allow by adhesive plaster. A pillow rolled lengthwise is strapped vertically to the middle of the back and a 3 pound sand bag laid on the front of the shoulder. This is kept on for three weeks and the patient then allowed to be up, with an axillary pad and swathe.

*Fractures of the Spine*—Two good reviews and summaries of our present knowledge of fractures of the spine and the therapeutic indications have appeared by Wilson<sup>84</sup> and Kleinberg<sup>85</sup>. Kleinberg questions the wisdom of ankylosing operations in the early cases, because thereby, though the time of convalescence may be shortened six months, five or six vertebral joints are made stiff instead of one or two only, by a longer but usually certain process of nature's healing, aided by artificial protection.

*Fractures of the Neck of the Femur*—Kleinberg<sup>86</sup> reports three cases of complete healing and cure of fractures of the neck of the femur as late as five months after injury. He employed Whitman's abduction method, applying the plaster after manipulation of the fragments and striking several blows with the mallet over the great trochanter as advised by Cotton.

Delbet<sup>87</sup> is of the opinion that fractures of the femoral neck proper never unite solidly when treated by immobilization alone, and advocates his peg or long screw insertion to hold the fragments together. He says that after immobilization alone, though the limb is a little short, the patients may walk on it for a time with little inconvenience, the stout capsule holding. Soon, however, this stretches and the primary shortening of 1 or 2 cm. increases to 6 or 7, with increased discomfort.

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83 Cotton and Brickley. Boston M & S J **185** 326 (Sept 15) 1921

84 Wilson. Canad M A J **11** 415 (June) 1921

85 Kleinberg. J Bone & Joint Surg **4** 80 (Jan) 1922

86 Kleinberg. Med Rec **101** 14 (Jan 2) 1922

87 Delbet. Progres med **36** 416 (Sept 3) 1921

**Historical Review** They quote Pott's original description to show that he described a fracture that does not exist. Dupuytren commended Pott and evidently thought that he had described the same lesion he himself was describing. Dupuytren was the first really to systematize the knowledge of ankle injuries. The type of ankle fracture most commonly seen was first described by Maisonneuve (1840), and it is safe to assume that both Pott and Dupuytren's descriptions applied to this fracture and not to the rather hypothetic type they thought they were describing. Maisonneuve was the first to invoke the external rotation of the foot held in the tibiofibular mortise in explaining the common oblique fracture of the fibula. The postmarginal fragment from the articular surface of the tibia had previously been described by Cooper, Destot, Chaput and others, before Cotton wrote about it. The authors review the work done by various investigators from Dupuytren down to the present, paying tribute to the convincing work done by Quenu, Homigschmied, Tillaux, and Maisonneuve.

**Mechanism of Fracture** After reviewing the anatomy of the ankle, the authors point out the fact that the motions which are likely to result in fracture are those of rotation of the foot and adduction and abduction. Inward rotation is a movement almost inseparable from the movement of adduction, as the anterior tarsal joints render the foot very mobile in this direction.

**External Rotation** Any movement toward external rotation converts the foot into a rigid lever, and motion with much force is transmitted to the ankle, the astragalus trying to turn in its long axis. Owing to physical laws of leverage, the greatest strain comes on the external malleolus. There is a push outward on the anterior border of the malleolus combined with a pull inward on the posterior border by the posterior band of the external lateral ligament. The resulting fracture by torsion is an oblique fracture of the fibula, running from above and behind, downward and forward, and it involves the inferior tibiofibular joint. Always it is higher behind than in front and usually extends in front to the external malleolus. The anterior tibiofibular ligament thus remains intact and there results no true diastasis between tibia and fibula. There is, at most, slight rotary displacement of the fragments. This is the most common fracture at the ankle (more than 25 per cent of all cases). If the force continues to act, the next lesion which is added is rupture of the internal lateral ligament, or, far more frequently, fracture of the internal malleolus, usually only of its anterior tip, seldom of its whole extent. The displacement may be slight or marked, and in many cases there is added the complication of fracture of the posterior margin of the tibia. (One or another variation of this type of fracture occurred in 100 of the 300 studied.) In these extreme types of fracture, disjunction of the tibia and fibula

may occur on avulsion of the anterior tubercle of the tibia. In such cases, the strain on the fibula is transferred higher up, and one may find fracture even in the upper third or just below the head of the fibula.

**Abduction Injuries (Fibular Flexion)** In these fractures, the influence of the tibiofibular ligaments is paramount. Straight abduction of the foot has, as its primary and most constant lesion, fracture of the internal malleolus or its equivalent, rupture of the internal lateral ligament. This is a prerequisite in order to free the astragalus sufficiently to permit it to press on the external malleolus. Following this: (1) If the tibiofibular ligament holds, the fibula breaks across through the external malleolus proper and not above these ligaments, as commonly taught, a bimalleolar fracture by abduction results. (2) If the tibiofibular ligament ruptures or the equivalent avulsion of the anterior tibial tubercle occurs and the force continues, the fibula breaks by flexion and the break usually occurs where the fibula is weakest, that is, above the inferior tibiofibular ligament in its lower third. Finally, as the most advanced stage, the entire lower end of the tibia may be torn off as the representative of the internal malleolus.

Separation of the fibula from the tibia by 3 cm. may occur, even with the posterior tibiofibular ligament intact. Owing to the almost indestructible nature of the posterior band of the external lateral ligament, almost never does a separation of the astragalus from the fibula take place. Diastasis does not, therefore, occur as a result of the astragalus being driven upward between the tibia and fibula as a wedge.

**Posterior Marginal Fragment of the Tibia and Posterior Displacement of the Foot** The mechanism by which this fracture is produced is almost certainly a crushing force acting from below upward. The size of the fragment varies from a small portion of the posterior lip to a large fragment. This fracture occurs quite frequently (in fifty-eight of 300 cases, or 19 per cent, and in fifty-one, or 50 per cent, of those conforming to low Dupuytren type). It may occur alone or in association with torsion or abduction fractures. Backward displacement of the foot cannot occur unless the astragalus is freed from the external malleolus by rupture of both the middle and posterior bands of the external lateral ligament, or unless the external malleolus is freed from the tibia by diastasis or by fracture of the fibula in such a way as to detach, with the lower fragment of the fibula, the fibular insertion of both the middle and posterior bands of the external lateral ligament, that is, in the Pott or Dupuytren type, or the mixed oblique type. A posterior marginal fragment favors displacement, but is not essential for it.

**Adduction Injuries (Tibial Flexion)** There is little dispute about the mechanism of these injuries. A tearing off of the external malleolus

is the first lesion, followed by a compression fracture of the internal malleolus, or a splitting upward of the tibial shaft occurs. The supra-malleolar fracture by adduction represents the most advanced type.

*Old Fractures of the Os Calcis*—Cotton's<sup>94</sup> attention has been attracted to poor results which are so common in fractures of the os calcis. More than half the patients with fracture of the os calcis suffer disability. Total disability for real work is the result in from 33 to 50 per cent of the cases. The causes of disability may be one or several. (1) The os calcis is a little short from front to back and a bit flattened. (2) Sharp outward deviation of the heel entails inevitable flatfoot. (3) Tender spurs on the plantar surface of the os calcis may result. (4) The common source of trouble is an outward broadening of the os calcis, owing to the shoving outward of the peroneal plate of bone and bone growth behind it. The external malleolus may impinge on the exuberant bone or be half buried in it, it may impinge only in flexion or extension, or it may pinch the peroneal tendons and their sheaths, invariably it is a factor in pain and disability. (5) Loss of some of the lateral motion is constant, resulting from alterations in the surfaces or clogging of the astragalocalcaneal joint. For correction he advises leaving shortened and flattened heels absolutely alone. Outward deviation calls for the Gleich operation, that is, an oblique osteotomy of the os calcis, with correction of the deformity. Spurs may need to be removed. For the troublesome outward broadening of the os calcis and clogging of the astragalocalcaneal joint, Cotton has developed an operative procedure. This consists in a curved incision under the external malleolus, elevating and turning upward a flap containing the peroneal tendons and their sheaths, periosteum and a thin layer of cortical bone. Then he digs out, wide and deep, the exuberant bone, disregarding the subastragaloid articulation, which is often narrowed by about half. The flap is then replaced and sutured and a plaster boot applied. At the end of two weeks, motion of the subastragaloid joint is begun. At four weeks, slight weight-bearing and at the end of six weeks full weight-bearing is permitted. He reports the cases of nine patients operated on, with one excellent result and six patients greatly improved, one failure, and one doubtful result in an old man.

*Spinal Fractures*—Rixford<sup>95</sup> has conducted an elaborate investigation of the mechanism of spiral fractures. He concludes that rarely can they be satisfactorily reduced without open operation, but when so reduced they are retained very easily with kangaroo tendon.

94 Cotton. Ann Surg 74 294 (Sept.) 1921

95 Rixford. Ann Surg 74 490 (Oct.) 1921

*Suspension Traction Treatment of Fractures of Long Bones Near Large Joints*—Hartwell<sup>96</sup> outlines the methods of suspension traction treatment carried out on his service at Bellevue Hospital in New York. He has become an advocate of skeletal traction in all cases of fracture of the femur. For intracondylar fractures of the lower end of the femur, he uses skeletal traction by means of a pin through the head of the tibia. For lower leg fractures, the skeletal traction is applied by means of ice tong calipers in the malleoli or os calcis.

*Influence of Physiotherapy in Reducing Disability Time in Fractures*—Wainwright<sup>97</sup> has compiled some rather interesting statistics from the Moses Taylor Hospital at Scranton, Pa. Before the establishment of a gymnasium and a physiotherapeutic department, the average time of disability in fractures of the clavicle was sixty-seven days, after the establishment, fifty-nine; humerus fracture, before, 125, after, 90; forearm fractures, before, 76, after, 64; femur fractures, before, 239, after, 180; lower leg fractures, before, 121, after 92.

This means a saving of actual time in the different types of from eight to fifty-nine days, and a percentage saving of from 12 to 28.

*Delayed Union and Nonunion of Fractures*—Nutter<sup>98</sup> considers very carefully the subject of delayed union and nonunion of fractures, pointing out the importance of discriminating between these two conditions. Delayed union may be expected in not much more than 1 per cent of all fractures, while nonunion occurs in from 2 to 3 per cent. The regions where nonunion is most prone to occur are between the middle and upper thirds of the humerus, the middle third of the femur, and in the lower third of the tibia and fibula. Fractures of the neck of the femur fail to unite solidly relatively very frequently. As to the causes of delayed or nonunion, Nutter considers that constitutional diseases, with the exception of syphilis, scurvy, acute rickets, osteomalacia, etc., exert little influence on union. Severe sepsis causes necrosis, but mild sepsis may actually stimulate callous formation. The local causes are the well recognized ones of nonapposition of fragments, interposition of tissue, imperfect immobilization, metallic plates, etc. For treatment of delayed union after proper conditions of immobilization have been satisfied, Nutter advises baking and other forms of hyperemia. Drilling the bone ends may be a help. He thinks there is little evidence to suggest that galvanism, ductless gland extracts, or injections of irritants are of service.

*Special Fracture Services in Hospitals*—Scudder,<sup>99</sup> who organized one of the first, if not the first, special fracture services in America, at

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96 Hartwell J. A. Suspension Traction, Arch Surg 3 595 (Nov.) 1921

97 Wainwright Ann Surg 74 304 (Sept.) 1921

98 Nutter J Bone & Joint Surg 4 104 (Jan.) 1922

99 Scudder Ann Surg 74 280 (Sept.) 1921



the Massachusetts General Hospital, has been impressed by the necessity of improving the results in the treatment of fractures throughout the country. He believes the carrying out of the following suggestions would be helpful: (a) special wards restricted to the treatment of fractures, (b) a special fracture personnel of surgeons under a chief of service of broad experience, (c) a special fracture outpatient clinic under the charge of the special fracture service, (d) an improvement in the methods of teaching fractures and more time for the subject in the medical school curriculum, (e) graduate courses for the general practitioner, (f) the organization of a clinical surgical fracture society, meeting once a year for the discussion of fracture problems.

*Medical Defense Aspect of Fractures*—An interesting indication of how important the problem of the proper treatment of fractures is becoming is shown from the review of Tuckerman<sup>100</sup> of the cases referred to the Medical Defense Committee of the Ohio State Medical Association. Of 107 matters so referred, forty represented dissatisfaction over the results of the treatment of fractures.

*Supernumerary Bones of Wrist and Ankle*—Holland<sup>101</sup> and Pirie<sup>102</sup> point out the importance of recognizing the rarer ossifications in the carpus and tarsus, representing true extra bones which may easily be mistaken for fractures. In the carpus, there may be mentioned the os centrale, the os triangulare, the ulnare externum, the radiale externum, the os vesalianum, and the divided scaphoid. In the foot, the os trigonum, the secondary os calcis, the tibiale externum, the os peroneum, the os vesalianum, and an ossicle without name.

#### MISCELLANEOUS

*Technic for Leg Amputation*—Orb<sup>103</sup> describes a method of leg amputation which he has found produces an excellent stump. An anterior skin flap is fashioned and a posterior muscle flap (gastrocnemius and soleus). This provides a posterior scar and a good muscle padding for the end of the bone with a fascial covering. He employs the Huber-Lewis technic for the prevention of neuromas, and the apertosteal method in the treatment of his bone end.

[ED NOTE—One of the Editors (Wilson) has independently devised the same method and has employed it, during the war and since, with great satisfaction.]

100 Tuckerman. *Ohio State M J* **17** 735 (Nov.) 1921.

101 Holland. *Arch Radiol & Electroth* **26** 105 (Sept.) 1921.

102 Pirie. *Am J Roentgenol* **8** 569 (Oct.) 1921.

103 Orb. *Ann Surg* **74** 633 (Nov.) 1921.

*Coalitio Calcaneonavicularis*—Slomann<sup>104</sup> of Copenhagen reports six cases of coalitio calcaneonavicularis or fusion of the os calcis with the scaphoid, illustrated by excellent roentgenograms. It is a congenital condition. The abnormality does not appear to show any particular preference for the right or the left foot. All his patients have been seen because of severe flatfoot deformities, and the flatfoot, both in regard to the degree of deformity as well as to clinical symptoms, has been most severe in the foot in which the anatomic abnormality was present or most pronounced. The ages of the patients were from 10 to 59 years. For treatment he has employed rest in plaster and has followed this with foot supports. He believes operative procedures may be necessary. In marked cases, the deformity is extreme. Slomann describes one case as follows: "The foot is 'of monstrous shape, short and enormously broad, with the convex rocker-shaped surface, the heel and tarsus rest on the ground, the first metatarsal bone tips upward at the mesial side of the foot and only the point of the downward bent great toe again reaches the ground'."

*Kohler's Disease*—Bauman<sup>105</sup> adds two cases to the list that has been growing since Kohler, in 1908, first described this unusual malformation of the tarsal scaphoid. Although he cannot explain the cause, his cases add to the evidence that is accumulating on the negative side, excluding syphilis, tuberculosis and osteomyelitis. He believes trauma to be the common cause, and cites its frequency in boys of the ages of 5 to 7. Trauma is little noticed, as is also the fact that the scaphoid is one of the last of the tarsal bones to ossify.

*Epicondylitis*—Aievoli<sup>106</sup> brings up for discussion the cause of pain in the region of the external humeral epicondyle occurring in tennis players and other sportsmen and in workers in certain industries. The pain is usually localized near the tip of the epicondyle, in the region of the origin of the radial extensors of the wrist and the common extensors of the fingers. He discusses the various etiologic theories. He considers the theory of Vulliet<sup>107</sup> of a bursa beneath the origin of the epicondylar muscles may be nearest the truth.

Osgood,<sup>108</sup> as a result of a personal experience, became convinced of the probable bursa nature of the syndrome, found bursae in seven consecutive cadavers, had his own elbow operated on, and bursal tissue found, and has operated on two other patients with positive findings.

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104 Slomann J Orthop Surg 3 586 (Nov) 1921

105 Bauman, G T Kohler's Disease, J A M A 77 1086 (Oct 1) 1921

106 Aievoli Riforma med 37 805 (Aug 30) 1921

107 Vulliet Semana med, June 2, 1909, p 261

108 Osgood R B Radiohumeral Bursitis, Epicondylitis, Epicondylalgia (Tennis Elbow), Arch Surg 4 420 (March) 1922

Schmitt<sup>109</sup> described a calcareous deposit over the epicondyle and believed the bursa to be between the epicondyle and the common extensor tendon. Osgood found his bursae beneath the conjoined tendon and the supinator brevis and radiohumeral joint capsule, where he believes it commonly is placed, and not directly over the epicondyle.

*Development of the Shoulder*—Cohn's<sup>110</sup> conclusions from a roentgenologic study of the normally developing shoulder are as follows. Radiologic examination of the shoulder during the first year shows only one epiphysis sufficiently ossified to leave a shadow, the epiphysis for the upper end of the humerus. This epiphysis is represented by a small elliptic shadow, which is rather widely separated from the upper end of the shaft. The earliest examination was at seven weeks after birth. During the first two years, no other epiphysis makes its appearance except for a small shadow which may be interpreted as the early ossification within the coracoid process. During the third year, the head of the humerus increases rather rapidly in size. The upper end of the shaft takes on the appearance of a double inclined plane, higher near the middle, and sloping downward to either side. At this time, there is a shadow on the lower aspect of the epiphysis for the head, which may be ossification within a separate epiphysis for the greater tuberosity or it may be that the greater tuberosity is a growth downward from the original epiphysis for the head. In the pictures no clear line of demarcation can be made out between the shadows. Beginning ossification within the coracoid is evident at 3 years. In order to avoid errors in interpretation of roentgenograms of the shoulder, one must take several views. Ossification within the epiphysis of the acromion is rarely evident before the middle of the fourteenth year. Complete ossification of the epiphysis of the acromion takes place about the middle of the eighteenth year. Complete ossification within the upper epiphysis is evident about the nineteenth year. There is no trace of the epiphyseal line at the twentieth year.

*Orthostatic Albuminuria*—Saito<sup>111</sup> concludes after careful study of a large group of children that patients showing orthostatic albuminuria have an asthenic condition, and about half of them show lordosis. A large majority of the patients are in a state of vagotonia and show a normal renal function and hemoglobin. Two methods are most reliable in provoking albuminuria. One is to have the patient hold a rod with the hands and lift it up to the level of the shoulder for ten minutes,

109 Schmitt Arch f Orthop **19** 215, 1921

110 Cohn Am J Roentgenol **8** 721 (Dec) 1921

111 Saito, H Clinical Investigations on Orthostatic Albuminuria, Am J Dis Child **22** 438 (Oct) 1921

the other is to have the individual kneel for ten minutes. The direct cause of albuminuria may be lordosis of the lumbar spine, but it is not altogether the essential factor. Vasomotor instability may be another

*Preventive and Prophylactic Orthopedic Practice*—Emmons and Goldthwait<sup>112</sup> call attention to the necessity of providing proper furniture in order to avoid postural strain, especially from work at a desk. They have planned a simple chair which they believe is practicable and helpful, and which they illustrate in their article.

Lowman<sup>113</sup> makes a strong plea for the recognition of postural defects and an attempt to correct them in the early years of school. Eighty per cent of all schoolchildren show one or more defects and many of the present physical instructors are poorly trained for correcting these faulty postures. He urges more interest among orthopedic surgeons in the training of these instructors and is convinced that the correction of these defects in childhood will do much to prevent the potential weakness which was so strikingly appreciated in the army recruits who failed to stand up to regular army life.

*Challenge of the Chronic Patient*—Goldthwait<sup>114</sup> begs the medical profession to focus its attention on the chronic patient, who has been so unsatisfactorily treated and generally considered hopeless. He points out that our study has been especially of the physiologic function of the body to find out where it is lacking and to discover some pathologic lesion of certain of the organs as a cause of the condition. As we are often not able to explain the imperfect function, the treatment is not evident. He urges that the mechanics of the body be more carefully studied and that attention be paid to the long existent attitude in which the bodily functions have been carried on. Pathologic conditions of the lower part of the back are the most common occasion for seeking medical advice. A persistent ptosis, or a malposition of the heavier viscera disturbing their blood supply, is a constant obstacle to proper function. We have the example in orthostatic albuminuria. It is probable that in many of the arthritic cases in which the patients do not recover after removal of foci in the tonsils or teeth, that no one organ is wholly at fault. A study of the individual anatomic habit will often give new significance to many of these symptoms.

*Journal Announcement*—The *Journal of Orthopaedic Surgery*, the official organ of the British and the American orthopedic associations, which up to January, 1922, had been issued monthly, has now become a quarterly and has changed its name to the *Journal of Bone and Joint Surgery*. It continues as the organ of the two associations and under the able editorship of Dr. E. G. Brackett.

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112 Emmons and Goldthwait. *J. Industrial Hygiene* 3: 154 (Sept.) 1921.

113 Lowman. *J. Orthop. Surg.* 3: 576 (Nov.) 1921.

114 Goldthwait. *Boston M. & S. J.* 186: 31-34 (Jan. 12) 1922.

## CORRESPONDENCE

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### "THE NEGATIVE CHAMBER IN OPEN PNEUMOTHORAX A PERSONAL EXPERIENCE"

*To the Editor* —My attention has been called by Dr Rudolph Matas, of New Orleans, to two historical errors which appear in my article, "The Negative Chamber in Open Pneumothorax A Personal Experience," in the July issue of the ARCHIVES OF SURGERY. I stated, page 134, that "the importance of preventing this physical phenomenon was fully realized by Dr Matas, more than twenty years ago, when, as one of the pioneers in the field of thoracic surgery in America, he had his assistant, Dr Parham of New Orleans, excise a tumor of the chest wall with the help of a differential pressure apparatus, the Fell-O'Dwyer combination, as modified by Matas." The fact is that Dr Matas and Dr Parham have been connected with the same hospitals and have served in them, contemporaneously, as colleagues, with the same rank and always in charge of separate and independent services. Dr Parham, therefore, performed his operation, July 24, 1898, independently, as a visiting surgeon in charge of his service at the Charity Hospital. Further, he did not employ the Fell-O'Dwyer apparatus, "as modified by Matas," but made use of it with good effect, though unmodified, in the form that was then being used at the Charity Hospital.

WILLY MEYER M.D., New York

# ARCHIVES OF SURGERY

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## OSTEOSCLEROSIS FRAGILIS GENERALISATA

MARMORKNOCHEN ALBERS-SCHONBERG DISEASE \*

GEORGE G DAVIS, A B, M D

CHICAGO

A patient who entered the hospital with a fracture of the right leg, the result of a rather trivial injury, giving a history of previous fractures, likewise following slight trauma, was found, on roentgen-ray examination, to have a pathologic fracture as the result of a rather obscure bone condition which has been termed osteosclerosis fragilis generalisata, Marmorknochen (marble bone), or Albers-Schonberg disease. Inasmuch as only nine other cases of this disease have been reported, all of which have been in the foreign literature, none in the English language, the history of this case is given, together with the roentgen-ray study of the entire skeleton and a review of the literature of this subject to date.

### REPORT OF CASE

*History*—W S, a schoolboy, aged 11 years, born in this country, was admitted to my service at the Cook County Hospital, April 20, 1922. He was brought to the hospital by his mother, who stated that, on April 18, 1922, he sustained an injury of the right leg. A playmate who was swinging him around became dizzy and fell with the patient, stepping on his right leg above the ankle. The patient had to be carried home, where he stayed in bed. He entered the hospital because of pain, tenderness and very slight swelling of the lower part of the right leg and inability to use it.

He sustained a fracture of both bones of the left leg in July 1920, when he fell out of a window, about 4 feet high, striking the middle of the left leg on a step. No physician was called at the time but a firm bandage was applied. He was unable to walk on the leg for three weeks. A fracture of the left femur occurred in November, 1920, when another boy pushed him against a fire hydrant. He was treated in St Elizabeth's Hospital at that time. The tonsils and adenoids were removed in 1918. He had a mild attack of appendicitis in 1917. He had had pneumonia seven times—at 4 months, 14 months, 3 years, 4 years, 6 years, and 10 years of age. With the last attack, he had an associated otitis media on the right side, at which time an "abscess was lanced." His hearing in the right ear at the time of examination was not so good as in the left.

He was essentially normal. His birth had been normal (a precipitate 10 pound baby). He was breast fed, his feedings being supplemented by cow's

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\* The author is indebted to Dr Arthur R Metz for the roentgenographic examination and the notes on it.

milk after three months and up to sixteen months, when he was taken off both the breast and the bottle. He usually stood high in his school work. He was in the high fifth grade.

His father and mother were both living and well. Two brothers were living and well. One brother had had "heart trouble." One brother died of pneumonia at 16 months. This brother was paralyzed on one side for a month, at 3 months of age.

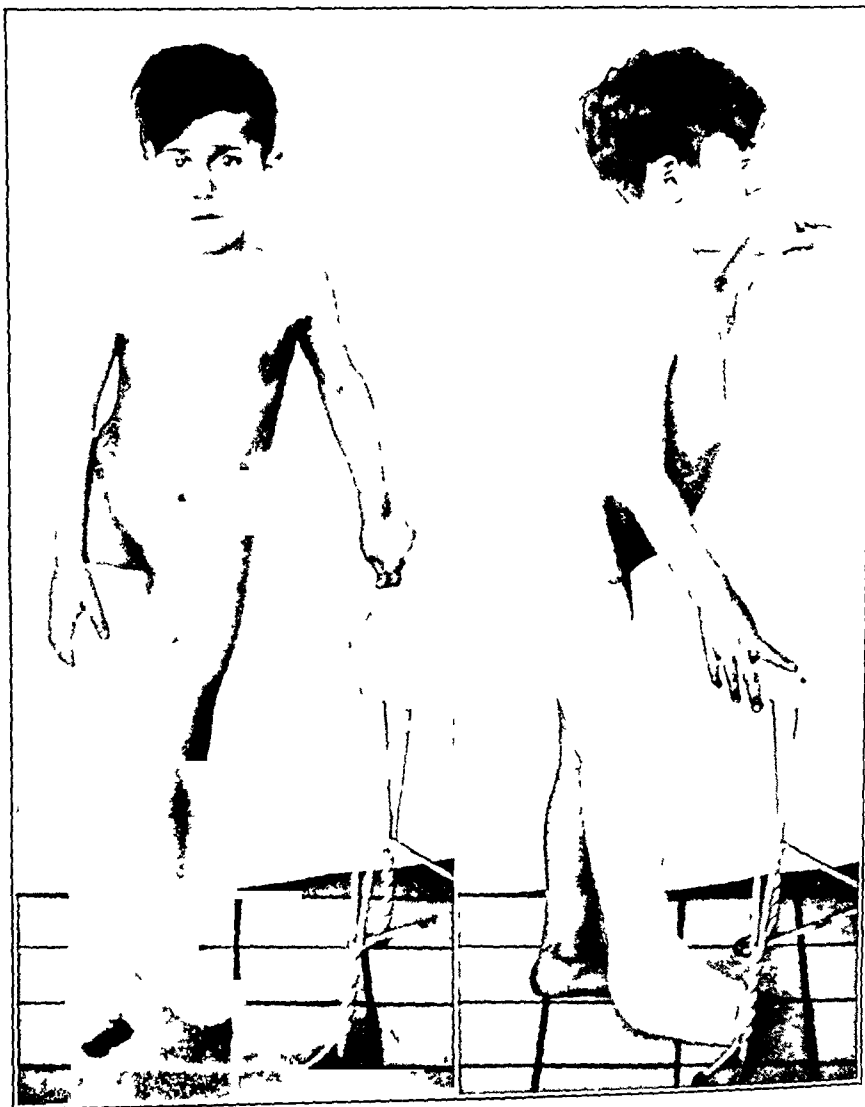


Fig 1—Left, anterior view of patient (W S), aged 11, with generalized osteosclerosis fragilis, right, lateral view of patient

*Physical Examination*—The patient was fairly well nourished, 3 feet 7½ inches tall (110 cm) and weighed 49 pounds (22 kg). There was loss of function of the right leg, with extreme pain and tenderness to touch over the lower third, with slight swelling but no deformity.

His head was large and had a long anteroposterior diameter. His eyes were brown and reacted well to light and on accommodation. The ears were negative externally, but there was an old otitis media on the right side. The septum

of the nose was deflected to the right. Many of the teeth were carious. The tongue was negative and the tonsils had been removed. The hard palate was extremely high. The cervical glands were palpable. The chest was symmetrical, except for a very slight scoliosis to the right in the middorsal region. A very slight suggestion of a Harrison's groove was present. The excursion and expansion of the lungs were good and there was no area of dullness or râles. The apex beat was within the nipple line, 5 cm to the left of the median line. There was no enlargement or murmurs. In the abdomen, there were no palpable tumors or areas of tenderness. The limbs were practically negative except for the pathologic condition noted above, and that the radial epiphyses were noticeably enlarged.

*Laboratory Findings*—The blood pressure was systolic, 128, and diastolic, 85. Hemoglobin was 86, erythrocytes, 4,992,000, color index, 86, leukocytes, 11,000. The urinary findings were negative. The specific gravity was 1.014, and the reaction acid. There was no albumin, sugar, acetone, diacetic acid, blood, cells or casts. The spinal fluid was clear and of normal pressure and gave a negative Wassermann reaction. The blood Wassermann reaction was also negative. The blood chemistry was total nitrogen, 34.30 (normal, 26.50), urea nitrogen, 21.48 (normal, 10), urea, 45.96 (normal, 21.40), uric acid, 1.95 (normal, 1.80), creatinin, 1.54 (normal, 1.35), sugar, 93 (normal, 100).

A blood Wassermann test on the mother gave a negative result.

July 10, 1922, an examination of the basal metabolic rate showed 52.5 calories, which is normal for a boy weighing 46 pounds, 44 inches high and 11 years old.

*Roentgen-Ray Examination*—This revealed a fracture of the right tibia at the juncture of the middle and lower thirds, without displacement of fragments, together with other pathologic conditions of the bone. A posterior molded splint was applied and the fracture showed union without much callus, the splint not being removed until June 21, 1922.

*Course*—About June 8, 1922, the patient developed severe pain and tenderness over the left scapula, associated later with redness, heat and fluctuation. The white blood count was 27,900, temperature, 99.4 F. Aspiration of pus revealed gram-positive cocci in staphylococcus formation. Cultures of pus revealed hemolytic colonies. Incision revealed a thick yellow pus.

*Diagnosis*—Pathologic fracture of the right tibia associated with osteosclerosis fragilis generalisata, old otitis media on the right side, probably old rickets, slight scoliosis of the middorsal spine, periostitis (?) of the left scapula.

*Roentgen-Ray Examination*—Roentgenographic examination of the entire skeleton revealed a generalized disturbance of the bony structure, characterized by a marked, irregularly increased density of some portions of the bones, with thinning and rarefaction in other areas. In the long bones, the tendency was toward a marked narrowing of the medullary canals in the middle third, due to a thickening of the cortex, with the ends of the shaft presenting an expanded appearance, with a thinning of the cortex and a coarsely mottled effect due to increased density in the marrow cavity. The small bones, such as the vertebrae, carpals, and tarsals, presented a generalized increased density with absence of bone structure. The epiphyseal lines were all present and were normal in width, but had slightly irregular margins. There was a general increase of density of the epiphyses, with absence of bony structure, but they appeared normal in size and outline. A detailed description of the bony changes is presented in the six roentgenograms, which altogether include the entire



skeleton, the bones of the hands, forearms and lower humeri are reproduced in Figure 2, feet, Figure 3, femurs and pelvis, Figure 4, legs, Figure 5, trunk, Figure 6, head, Figure 7

In the examination of the hands, forearms and lower humeri (Fig 2), the following pathologic findings were noted. The structural contour of the phalanges was preserved, though the phalanges themselves were thickened. The

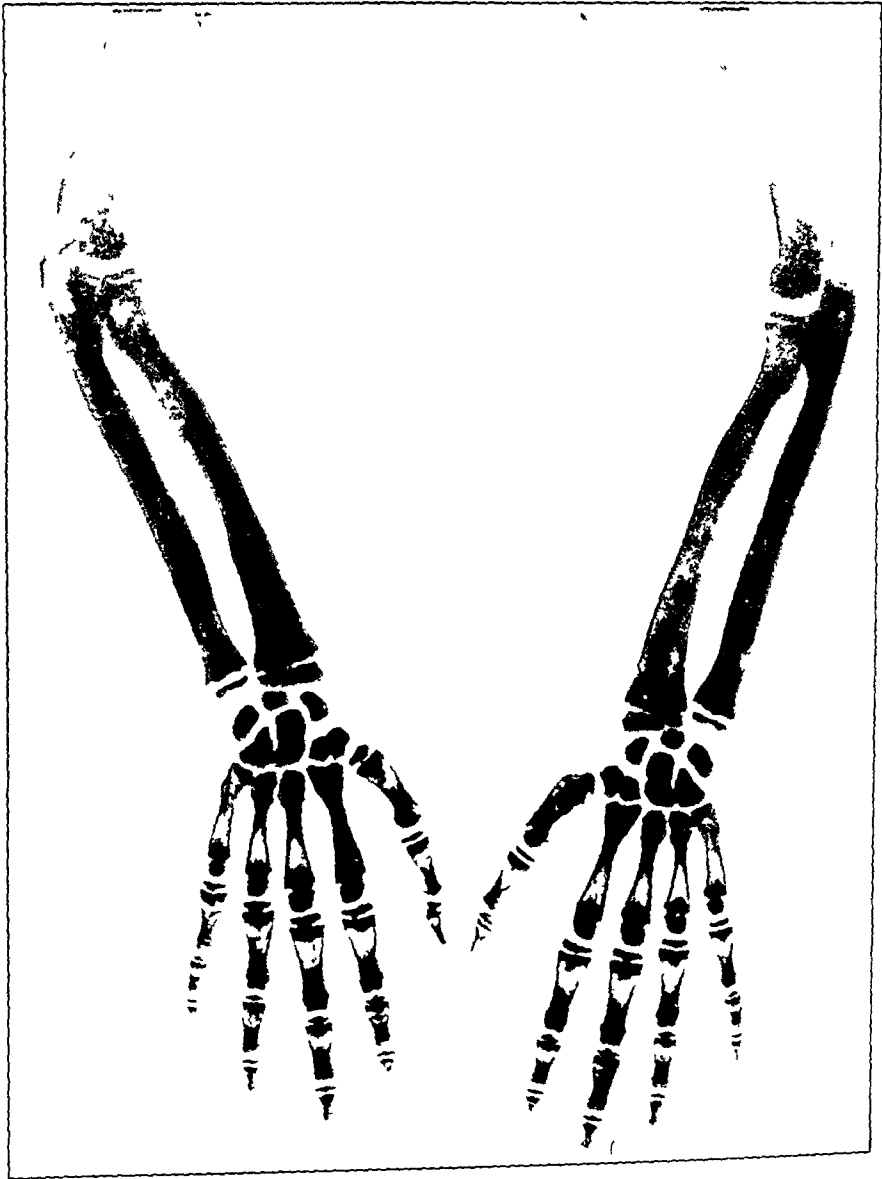


Fig 2—General marble-like picture of the bones of the hands, forearms and arms, transverse, parallel, disklike bands in the phalanges and metacarpals, fracture of the distal epiphysis of left radius

medullary portion was changed to compact bony tissue at the distal ends of all phalanges. This occurred in such a manner that it left a triangular area of lesser density at the proximal end of each phalanx, with the base of the triangle at the proximal end of each phalanx and the apex pointing toward the distal end. At the apexes of these triangles, small isolated areas of calcification were noted, especially in the proximal phalanges. At the base of these triangles,

parallel, transverse bands of lime deposits were noted. These were especially marked in the thumbs. Parallel hairlike lines also ran from the base of this triangle toward the apex. The proximal ends of the bodies of the phalanges at the base of the triangle described were structureless and of marble-like density, as were also the centers of ossification for the proximal ends of the bone, a well defined line separating the former from the latter.

The metacarpals showed similar changes, the greater portion of the bones presenting a marble-like density. The distal extremities of each of the second, third, fourth and fifth bones, corresponding to the distal center of ossification, showed great density. Similarly, the proximal, or epiphyseal, portion of the

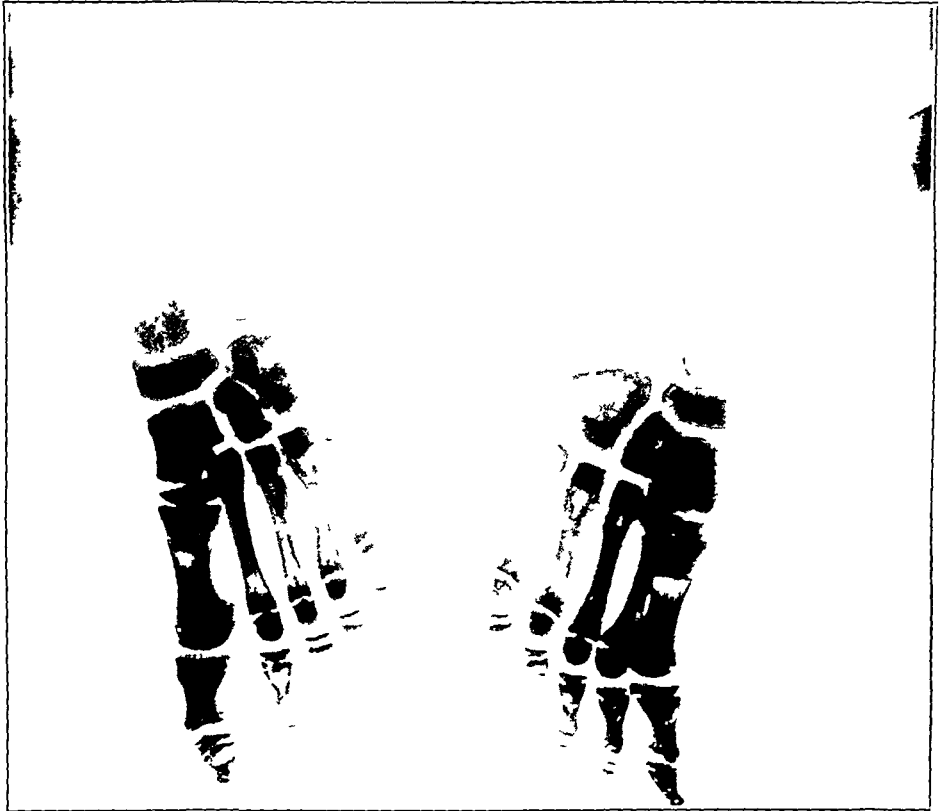


Fig 3—General marble-like picture of the bones of the feet, parallel lines of calcification running in superimposed disklike fashion at the base of the first metatarsals, peripheral and central calcification of the cuboid bone, with an area of lesser density between

first metacarpal showed great density. A triangular area of lesser density, with its base at the distal end of the bodies of the metacarpals, was noted in the metacarpal bones corresponding to the fingers. The base of the triangle of light area in the metacarpal corresponding to the thumb was toward the proximal end of the body of the bone and presented well defined disklike, parallel, transverse bands of calcification. There was a trace of a distal epiphyseal line in each of the first metacarpals.

The carpal bones presented a compact, structureless mass of marble-like density.

The epiphyses of the radius showed the same marble-like density and a well defined epiphyseal line in the upper portion, not so well defined in the lower. The lower epiphysis of the left radius was definitely shown to be fractured, although the patient made no complaint of this.

The diaphysis of each radius was curved slightly toward the radial side, and was very dense, the medullary canal being almost obliterated in pro-

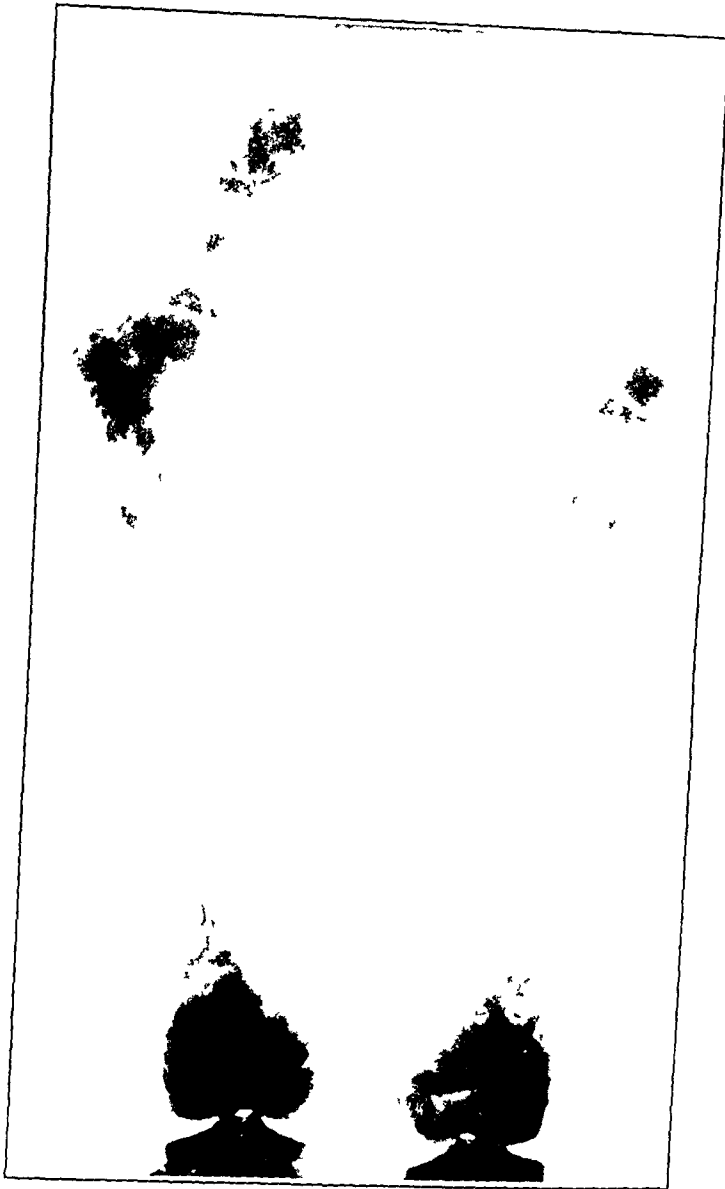


Fig 4—Hour-glass-like narrowing of the medullary canal due to thickening of the cortex in the middle third of the femur, and transverse layers of increased density in the expanded distal portion of the medullary canal, increased density of the pelvis

portion to the thickening of the corticalis. Each ulna presented a picture similar to that of the radius. There was more or less clubbing of the upper ends of both bones of the forearm. Peri-articular calcification of the elbow joint was noted in the area between the head of the radius and the capitellum. The lower end of each humerus, although preserving its normal contour, showed

the same marble-like density, the medullary canal being very narrow, with a corresponding thickening of the compact substance

The examination of the feet (Fig 3) revealed a picture quite similar to that noted in the hands. The disklike, parallel, transverse shadows at the proximal ends of the first metatarsals were particularly well defined. The tarsal bones, with the exception of the cuboid, showed the same compact,

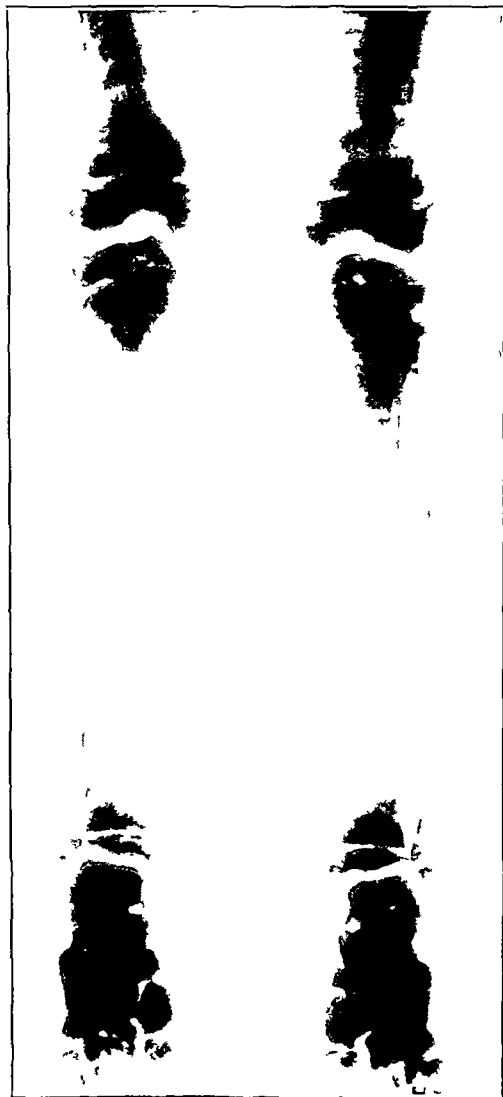


Fig 5—Pathologic oblique fracture through the distal third of right tibia, outward bowing of the shafts of the tibia and fibula, increased density of the long bones, marked increase in density of the epiphyses

structureless, dense, marble-like condition noted in the carpal bones. The cuboid showed a peripheral shadow which, toward the inside gave place to a lighter area which again showed a greater density in its center. There was no calcification of the tendon of Achilles at its insertion, as noted by Schulze in his case.

The femurs (Fig 4) were symmetrically involved, with a marked increased density of the proximal and distal thirds, with an hour-glass-like narrowing of the medullary canal in the middle third, due to a thickening of the cortex. Toward each end, the cortex was gradually thinned and the medullary canal correspondingly expanded. This was most marked in the distal portion. In this expanded medullary canal, there were seven irregular, transverse layers

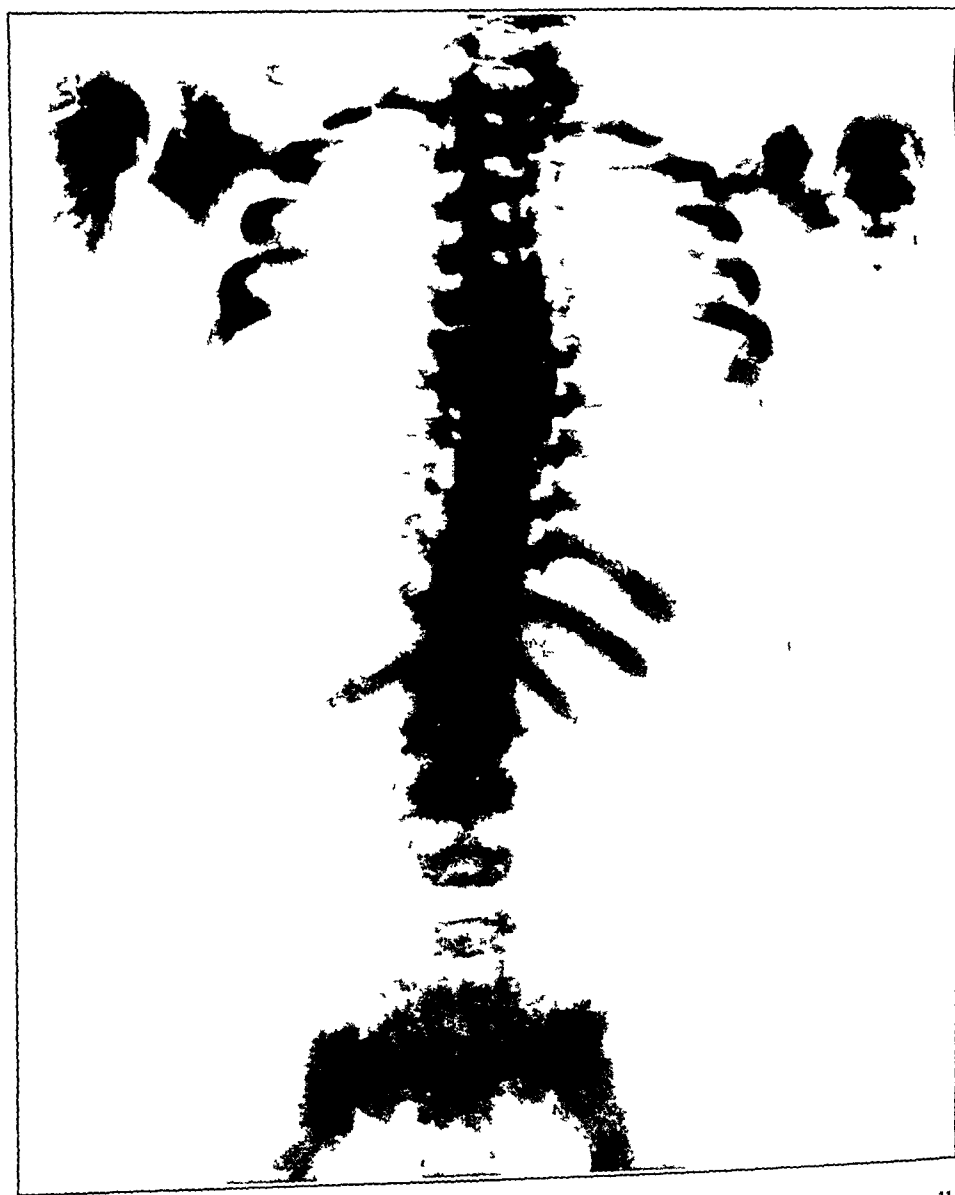


Fig 6—Scoliosis of the dorsal spine, ribs larger and denser than normally with the absence of bony structure, increased density of scapulas, most pronounced about the head and coracoid process, humeri similar to femurs

of increased density, about 1 cm in width, which may have represented periods of growth. There was an absence of normal bone structure. The epiphyseal lines appeared normal. The distal epiphyses were markedly increased in density, with absence of bone structure. The proximal third presented a more uniformly increased density than the distal, with absence of the transverse layer formation, and a less marked thinning of the cortex. The epiphyses of

the head and great trochanter presented the marked dense appearance, with absence of bony structure. There was no bowing or evidence of injury and the margins were smooth in outline.

The pelvis was normal in size and shape, presenting a marked increase in density. The margin of the crests of the ilia was irregular in outline. In the central portion of each wing, there was a circular area, 3 cm in diameter, which was less dense and appeared like normal bone about which were concentric layers of increased density which suggested periods of growth.



Fig 7—Skull showing a definite increase in density about the base of the middle and frontal fossae, posterior and anterior clinoid processes enlarged, increased in density, the posterior, a clublike prominence

The tibiae (Fig 5) were similar in appearance, except for an oblique fracture extending for a distance of 8 cm through the distal third of the right. The fragments were in good position and there was evidence of callus formation. There was definite bowing outward of the shaft. The middle third was similar in appearance to the femurs. The proximal third presented a similar appearance to that of the distal third of the femur, having the indistinct transverse layers of increased density, of which five could be identified. In

the distal third, the density was irregular and presented no suggestion of layer formation. The epiphyses were markedly increased in density, with absence of bony structure.

The fibulas presented the same general characteristics as the femurs and tibias. There was a slight scoliosis of the spine (Fig 6), and the bodies of all the vertebrae showed a marked increase in density. The ribs were larger and denser than normal, with absence of bony structure. There were the same general changes in the clavicles that were common to the other long bones. The scapulae showed increased density, which was most pronounced about the head and coracoid process. The humeri were symmetrically involved, the proximal two-thirds having an appearance similar to that of the distal portion of the femur, while the distal third showed less change.

The skull (Fig 7) showed a definite increase in density about the base of the middle and interior fossae. The anterior and posterior clinoid processes were larger and more dense than normally, the posterior appearing as a clublike bony prominence. The fossa for the pituitary gland was 8 mm in diameter. The area of the sphenoidal sinus showed a uniformly increased density, leaving no evidence of a cavity. The mastoid areas were similar in appearance, with an increased density and no evidence of mastoid cells. The coronal and lamboid structures were very distinct and appeared normal, as did also the grooves of the meningeal arteries. The vault appeared normal, having a good bony structure, and it was the only part of the skeleton that did appear normal.

These changes showed that there had been a generalized disturbance in the bone forming elements, in which there was an increased bone production, together with a thinning out of the structure in other parts, leaving the bone rather fragile, as is demonstrated by the oblique fracture of the right tibia, which was the result of a very minor injury. If the layer formations which could be demonstrated are interpreted as periods of growth, each of a year's duration, we may conclude that the process had been going on for about seven years.

#### LITERATURE

In 1904, Albers-Schonberg<sup>1</sup> presented roentgenograms of a rare bone disease which hitherto had been undescribed. A man, aged 26, fell into a shallow rut and fractured the femur. Roentgen-ray examination revealed that the bony structure was not recognizable. The bones gave deep, black shadows, the medullary cavity was lacking, the corticulis was diffused. Examination of the entire bony structure revealed a fracture of the other thigh and one of the olecranon. Of the origin of these the patient knew nothing.

Besides the deep, dark bone shadows, there were several transverse rings visible on the shorter bones of the extremities, as well as on the ribs. The whole picture suggested an unusually pronounced calcification of the whole skeleton.

In 1907, Albers-Schonberg<sup>2</sup> enlarged on the earlier report (1904) of his patient, who now enjoyed perfect health, and worked as a

1 Albers-Schonberg. Röntgenbilder einer seltenen Knochenerkrankung, München med Wchnschr 51 365, 1904.

2 Albers-Schonberg. Eine bisher nicht beschriebene Allgemeinerkrankung des Skeletts im Röntgenbilde, Fortschr a d Geb d Röntgenstrahlen 11 261, 1907.

merchant without any trouble. Symptoms given in the first description were still unchanged. He adds the picture of the condition of the skull, which is peculiar in the region of the sella turcica. The posterior clinoid process consisted of a club-shaped solid bony prominence, which apparently indented the region of the sella. The crista galli also showed the same changes. The other bones showed a marble-like character.

In conclusion, Albers-Schonberg emphasized besides the marble-like changes of the bones, the especially characteristic appearance of parallel bands of lime in the diaphyses of the bones of the hand, of the feet, of the fibula and on the ribs. He emphasized the fact that these were the result of especially dense lime deposits. The etiology of this condition is not known.

In 1913, Schmidt<sup>3</sup> reported a case. He wished to introduce the name of "lime gout" because of the similarity between the process in extensive lime deposit due to metabolic disturbances, and the genuine uric acid gout.

The case reported by Schmidt was that of congenital osteosclerosis, in which the long pipe bones were less affected than the vertebrae, the base of the skull and the sternum. The child was well developed, and died thirty hours after birth. The blood was that of a normal cadaver. The bone marrow showed a physiologic cell synthesis without signs of a fibrous change or a leukemic or pseudoleukemic disease. There was also enlargement of the hypophysis.

In 1914, Sieck<sup>4</sup> reported three cases of a rare disease of the skeleton.

CASE 1—A girl, aged 15, undeveloped for her years, had been apparently well in early youth. Her growth was impeded when 5 years old by a slight fracture of the femur. In the course of the years, she had fourteen other fractures. There was gradual increase in defect of eye-sight. During the last two years, suppuration of the lower jaw had occurred, causing almost all the teeth to fall out. Ophthalmoscopically, considerable optic nerve atrophy was revealed. Roentgen-ray examination revealed complete, structureless skull bones. The sella turcica was narrowed. The clinoid process projected greatly. The femur, tibia and fibula of both sides showed club-shaped thickenings. In the lower half of the tibia, parallel to the middle of the diaphyses, were convex streaks. The epiphyses, as well as the diaphyses were without structure and only in the lower third of the leg (below the knee) could the corticalis and medullary space still be distinguished. In the upper extremities were different, deformed, healed fractures. The upper half of the humerus was thickened like a club, and the lower half showed transverse striations, like the tibia, with the concavities toward the diaphyses.

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3 Schmidt, M. B. Kalkmetastase und Kalkgicht. *Deutsch. med. Wchnschr.* 39: 59, 1913.

4 Sieck. Ueber drei Falle einer seltenen Skeletterkrankung (Marmor-knochen nach Albers-Schonberg). *Festschrift zur Feier des 25 jährigen Bestehens des Eppendorfer Krankenhauses*. 1914.



CASE 2 — A boy, aged  $3\frac{1}{2}$  years, with hydrocephalus, great decrease in vision, and beginning optic nerve atrophy, presented a perceptibly enlarged posterior clinoid process. The base of the skull and the skeleton of the face were thickened and structureless. The humerus in its upper end was club-shaped. The metacarpals and phalanges were thickened. The talus, calcaneus and cuboid showed, in the roentgenogram, a peripheral shadow which, toward the inside, gave place to a lighter area so as to show again a thickening in the center.

CASE 3 — A girl, aged  $2\frac{1}{2}$  years with hydrocephalus and optic nerve atrophy, presented a narrowed sella turcica, but not so pronounced as in Case 2. The posterior clinoid process, however, was plainly enlarged. The bones of the skull and extremities were of the same structureless nature as in the preceding case. This patient and the patient in Case 2 were brother and sister.

Sieck believes that the fine parallel streaks in the diaphyses are zones of growth.

In 1915, Reiche<sup>5</sup> described a case of osteosclerosis and anemia.

The patient was a man 37 years old, mentally active. He was delicately built and looked pale. He was married and had no children. He had an excessive appetite, and required a great deal of sleep. Roentgenograms revealed thickening of the bones. In the left groin was a tumor the size of a child's fist, which was sensitive to pressure. The liver projected about one and one-half finger breaths over the right costal arch.

The condition of the blood was as follows. The hemoglobin content was permanently decreased and varied between 30 and 36. Microscopically, the red blood corpuscles varied greatly in size. Erythrocytes were seen in some of the preparations. Blood platelets were present in abundance. The number of polymorphonuclear leukocytes was permanently decreased, which multiplied the number of lymphocytes.

Reiche concludes that no peculiarity in the blood picture exists in cases of osteosclerotic anemia, and that so far roentgenography is the best procedure to determine the characteristic marble-like density of the bones.

In 1917, Pick<sup>6</sup> called attention to the fact that it could not be proved macroscopically that the changes in the bone were responsible for the appearance of the lime deposits, and that they reminded one of the picture of classical lime metabolism. Schulze<sup>7</sup> found double the normal lime value of the blood in his case, and, in considering the progressive exhaustion of the bone substance and the enrichment of the blood with lime salts, he suggests that this follows a low grade of activity of the osteoblasts, and the lime is incompletely utilized in forming new bone substance.

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<sup>5</sup> Reiche, F. Osteosklerose und Anämie, München med Wchnschr 62 944 (July 13) 1915.

<sup>6</sup> Pick, L. Die indikatorische Bedeutung der Kalkmetastase für den Knochenabbau, Berlin klin Wchnschr 54 797, 1917.

<sup>7</sup> Schulze, Fritz. Das Wesen des Krankheitsbildes der "Marmorknochen (Albers-Schonberg)," Arch f klin Chir 118 411, 1921.

In 1920 Laurell and Wallgren<sup>8</sup> described a disease of the skeleton originally observed in a boy of 12. The skeleton showed general fragility, with a marble-like appearance.

Ernst E., aged 12 years, was the third of five children. The other children were healthy, without any sign of rickets or other bone disease. The family history was negative. At one-half year, he had not developed much since birth. He was pale and irritable and cried all day long. The head seemed to grow, although the body did not. Up to the age of 5 or 6 years, the skull circumference increased very noticeably. At about 1 year of age, his mother noticed that he had nystagmus. After his second year, it was discovered that his vision was defective. At 2½ years he could walk and talk quite well. At the age of 1 year his first teeth appeared, and the rest came in slowly and irregularly. At 3 years of age, his parents consulted a physician who diagnosed his case as rickets and hydrocephalus and prescribed cod liver oil. No great improvement followed. In 1915, when the boy was 8 years old, he fell backward down the stairs and fractured the right femur, for which he was treated for eight weeks at the hospital and was then discharged with good callus formation. The next year he broke his left leg. This fracture also healed. In the following year he suffered still another fracture of the left leg. In 1918, the right femur was fractured, this healed after six weeks. In July, 1919, without known injury or accident, the right femur was again fractured. He was sent to the hospital, the fracture healed, and he was then transferred to the children's ward.

Roentgen-ray examination revealed old fractures in other parts of the skeleton. On admission, the boy seemed in good general condition, with poor musculature. He was 122 cm tall and weighed 23.3 kg. He was afebrile, the pulse was 100. His head was large in proportion to the rest of his body. It measured 57.5 cm in circumference. When he looked to the side a slow nystagmus was present. When he looked toward the left, this was especially marked. The pupils were wide and reacted normally to light. Vision was limited. There was a bilateral choked disk in the atrophic state, moderate bilateral rhinitis, poor teeth and stomatitis. The tonsils were small and smooth. There was marked lordosis of the lumbar spinal column when he stood. The thorax was deformed, with a deep depression along the insertion of the diaphragm, and a corresponding bulging forward of the edges of the thorax. The abdomen was slightly distended but not painful. The skin and tendon reflexes were active. The Babinski sign on the right was negative, on the left, uncertain. The lungs were normal except for a slight basal bronchitis. The heart sounds were distinct. The blood pressure was 100. The spleen was palpable. The liver was not enlarged. The sexual organs were normal. The Wassermann reaction was negative, the Ross-Jones reaction was negative. Detailed roentgen-ray findings are given.

Examination revealed the fact that the thyroid was nonpalpable. All osseous structures showed an enormous deposition of lime especially in the cranium and trunk. There was a history of hydrocephalus. The long bones showed condensed lime rings and lateral bands. Experiments were made with the view of determining a possible retention of lime, but the result was nega-

<sup>8</sup> Laurell and Wallgren. Untersuchungen über einen Fall einer eigenartigen Skeletterkrankung (Osteosclerosis fragilis generalisata), Upsala Läkartidn. Forh. 25:309 (Nov. 8) 1920.

tive The diagnosis, founded on history and feeding experiments, was initial rachitis, complicated by hydrocephalus and a fundamental disturbance of the glands of internal secretion thyroid, hypophysis and perhaps others, resulting in lime condensation, and some secondary symptoms (serous meningitis, atrophy of the optic nerve, anemia)

Four similar cases are known Eight roentgenograms show the pathologic structure

In 1921, Schultz<sup>7</sup> discussed the nature of the disease of marble bones (Albers-Schonberg) and reported a case

Hugh S, aged 11 years, of healthy family, mentally well developed, had always been well In 1914 he had scarlet fever Ever since that time he had been sickly He was sent to the hospital for disease of the lungs There was no improvement There was slowly increasing stiffness of the vertebral column and visible emaciation

At the time of examination the vertebral column showed a right scoliosis of the upper thoracic vertebrae The patient was confined to bed The teeth were decidedly rachitic Calcification of the ligament of the patella and the Achilles tendon at insertion showed in the roentgenograms, also calcification of the posterior longitudinal ligament of the vertebral column and the plantar ligament was noted

The ossification of the vessels appeared as a secondary condition, compared with the changes in the entire skeleton With the exception of the metaphyseal regions the corticalis and medullary space had disappeared in all the long pipe bones The bones were changed into a compact, structureless, bony mass These changes also appeared in the short bones, such as the vertebrae and bones of the feet The axes of the femur, fibula, tibia and forearms showed indistinct curvature The head of the humerus showed club-shaped thickenings The head of the left femur stood in coxa-valga position

Necropsy revealed that the degree of thickness of the bone substance was increased, inasmuch as there were lime deposits in the marrow spaces, which in places completely filled the marrow space, with the exception of very small blood vessel canaliculi This lime deposit rested partly on the wall of the arteries but was independent of the condition of the medullary tissue Bone changes were found in the whole skeleton The posterior clinoid process and the sella turcica showed clublike thickenings, which authorities believe cause a decrease in function of the hypophysis

Worthy of notice was the considerable narrowness of all the foramina of the base of the skull This narrowing seemed to justify the conclusion that the optic nerve atrophy, which is so often noticed, might be due to bony pressure upon the optic nerve Schulze believes that the slow bone formation is responsible for the increase in the lime content in the blood and can be considered as a final result of defects in the lime metabolism

In this disease, according to Virchow,<sup>9</sup> the normal excretion of lime

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9 Virchow Die Kalkmetastase, Virchows Arch f path Anat 81 618, 1856, *ibid* 81 103, 1855

salts is reduced because of inflamed or diseased kidneys, an accumulation of these salts in the blood occurring as a consequence. It has been shown, however, that marked disturbances in lime metabolism are possible even when the kidneys are not diseased. The kidneys in the case observed by Virchow presented a hyaline degeneration of the glomeruli due to an obliterating endarteritis and calcification. The process which at first seemed dependent on an excess of lime salts in the blood caused extensive calcification of the vessels.

According to Reiche, the osteosclerosis in his case was caused by myelogenous leukemia or pseudoleukemia, but this is not very probable. On the contrary, there exists a similarity between this condition and rachitis, as is shown by the condition of the proliferative cartilage zone.

Microscopically, the formation of the periosteal new bone is very slight. The bone very often appears to be incomplete because of the imperfect bone corpuscles. The cambium layer of the periosteum is distinctly recognizable, but shows flat, spindle-like cells, without any very active zones of proliferation.

According to Lorey,<sup>10</sup> cited by Schulze, the three children reported by Sieck died with symptoms of anemia due to maxillary necrosis, with protracted suppuration. Lorey reports the findings in a brother of the girls in whom he could observe great thickening of the skeletal system, so that no separation between corticalis and spongiosa was possible.

Especially noticeable was the even thickening of the calcaneus and talus, which did not show a light place in the center, as in the two sisters. The streaks running transversely, which in the other cases were very plain, were not visible in this case. There was increased intraspinal pressure, and optic atrophy in a few weeks caused blindness. The child died at the age of 5 months, after a severe anemia and necrosis of the maxilla with suppuration. Necropsy was not performed.

<sup>10</sup> Lorey. Ueber eine sehr seltene Allgemeinerkrankung des Skeletts (Marmorskelett), *Verhandl. der deutsch. Röntgen-Gesellschaft*, cited by Schulze. *Arch. f. klin. Chir.* **118**: 413, 1921.

OSTEOPSATHYROSIS REPORT OF A CASE  
WITH ROENTGENOGRAMS OF ELEVEN DIFFERENT FRACTURES  
IN THE SAME PATIENT

DONALD M GLOVER, M D

BOSTON

The accompanying case of osteopsathyrosis was treated and studied in the surgical outpatient department of the Children's Hospital, Boston. The accompanying series of roentgenograms gives a graphic fracture history of the patient from the time he was 9 months old until his death, at 7½ years.

In spite of the large number of cases reported in the literature, osteopsathyrosis, or fragilitas ossium, is a relatively uncommon cause of pathologic fractures. Griffith<sup>1</sup> and Ostheimer<sup>2</sup> had collected 193 cases in all up to 1913, and since then a few cases have been reported. In 1913 one case was reported by Schwarz and Bass,<sup>3</sup> and another by Bamberg and Hulschinsky.<sup>4</sup> In 1914 Bookman<sup>5</sup> reported one, and the following year Kienbock<sup>6</sup> collected thirty-seven cases from the literature (from 1888 to 1914) and added two cases of his own. Blaine<sup>7</sup> reported one case in 1916, and, in 1917, Hess<sup>8</sup> presented four cases and Mixsell<sup>9</sup> two. In 1920 Ruggeri<sup>10</sup> reported one, and in 1921 Vander

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\* From the surgical service of the Children's Hospital, Boston, under the direction of Dr. James S. Stone. The roentgenogram reproduced in Figure 12 is used through the courtesy of the Massachusetts General Hospital.

1 Griffith, J. P. C. *The Diseases of Infants and Children*, Philadelphia, W. B. Saunders Company 2: 432, 1919.

2 Ostheimer, Maurice. *Fragilitas Ossium*, J. A. M. A. **63**: 1996 (Dec. 5) 1914.

3 Schwarz, Herman, and Bass, M. H. *Osteogenesis Imperfecta*. Report of a Case with Study of Its Metabolism, *Am. J. Dis. Child.* **5**: 131 (Feb.) 1913.

4 Bamberg, K., and Hulschinsky, K. *Ueber angeborene Knochenbrüchigkeit*, *Jahrb. f. Kinderh.* **78**: 214, 1913.

5 Bookman, A. *The Metabolism in Osteogenesis Imperfecta with Special Reference to Calcium*, *Am. J. Dis. Child.* **7**: 436 (June) 1914.

6 Kienbock, R. *Ueber infantile Osteopsathyrose*, *Fortsch. a. d. Geb. d. Röntgenstrahlen*, Hamb. **23**: 122, 1915.

7 Blaine, E. S. *Idiopathic Infantile Osteopsathyrosis*, *Am. J. Roentgenol.* **3**: 438 (Sept.) 1916.

8 Hess, J. H. *Osteogenesis Imperfecta*, *Arch. Int. Med.* **19**: 163 (Feb.) 1917.

9 Mixsell, H. R. *Osteogenesis Imperfecta with Report of Two Cases*, *Arch. Pediat.* **34**: 756 (Oct.) 1917.

10 Ruggeri, E. *Idiopathic Osteopsathyrosis*, *Pediatrics* **28**: 953 (Oct. 15) 1920.

Veer and Dickinson<sup>11</sup> reported one. There have doubtless been others that I have overlooked. In other words, more than 200 cases of osteopsathyrosis have been reported. Contrasted with this apparently large group, we find that in a series of 45,000 births in the Gottingen Frauenclinic, Birnbaum<sup>12</sup> found only one case of fragilitas ossium. Again, in a series of 1,610 long bone fractures (including the clavicle) treated at the Massachusetts General Hospital, only two fractures due to fragilitas ossium are recorded.<sup>13</sup>

#### REPORT OF CASE

*History*—The family history was of no significance. The father, mother and five other children were living and well. There was no history of bone disease, fractures or blue sclerae anywhere in the family. The patient was a full term baby and was delivered normally. He was breast fed for fourteen months. He had had measles, but no other illnesses, except for the fractures he had sustained. His lower, central incisor teeth were present at birth. About a year ago they had come out, and none had replaced them.

When 9 months old, the patient fell, fracturing the left femur just above the condyles (Fig 1). A plaster spica was applied in the surgical outpatient department of the Children's Hospital, and union resulted, with practically no deformity.

When 21 months old, he was jumping on the porch steps, when he began to cry and to hold up his right leg. He did not fall, but he would not use his right leg after that. The roentgen ray revealed a fracture at about the junction between the upper and middle thirds of the right femur, with slight anterior bowing (Fig 2). He was admitted to the hospital, where a plaster spica was applied with a pad over the site of the deformity. At that time both femurs showed some anterior bowing, which Dr James S Stone then attributed to rickets (Fig 3). A small cystic rarefaction was noted at the lower end of the left femur.

Soon after discharge from the house, in the following month, the roentgen ray revealed shadows about the site of the fracture, which were rather more extensive than might be expected from callus formation alone (Fig 4 A). Three months later he was again admitted because of a definite tumor mass that had formed at the point of fracture. Because of the possibility of new growth, the tumor mass was excised. Pathologic examination, however, demonstrated the specimen to be callus and not new growth (Fig 4 B). At about this time, the patient complained of inability to flex the right forearm, but there were no clinical signs of fracture. No roentgen-ray examination was made. After immobilizing the arm with an internal angular splint for a few days, all symptoms disappeared.

When 2 years and 9 months old, the patient complained of some pain in the left thigh. The roentgen ray disclosed slight raising of the periosteum along the middle third of the left femur (Fig 5). A plaster spica was applied and kept on for two months, after which time all symptoms abated.

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11 Vander Veer, E. A., and Dickinson, A. M. Fragilitas Ossium, *Ann Surg* 74:629 (Nov.) 1921.

12 Birnbaum, R. A Clinical Manual of the Malformations and Congenital Diseases of the Foetus, Philadelphia, P. Blakiston's Son & Co., 1912, p. 246.

13 MacDonald, R. F. Unpublished series of pathologic fractures.

When 3 years old, he fell to the floor from a standing position. His left arm swelled considerably, but the swelling disappeared within a few days, and the function seemed practically normal again. A roentgenogram, taken one week later, revealed a fracture of the left radius, with some lateral displacement but no overriding (Fig 6). Good union was obtained with antero-posterior splints.

When he was 4 years old, he fell again, and a green-stick fracture of the left radius resulted (Fig 7). This fracture united quickly without deformity, after splinting.

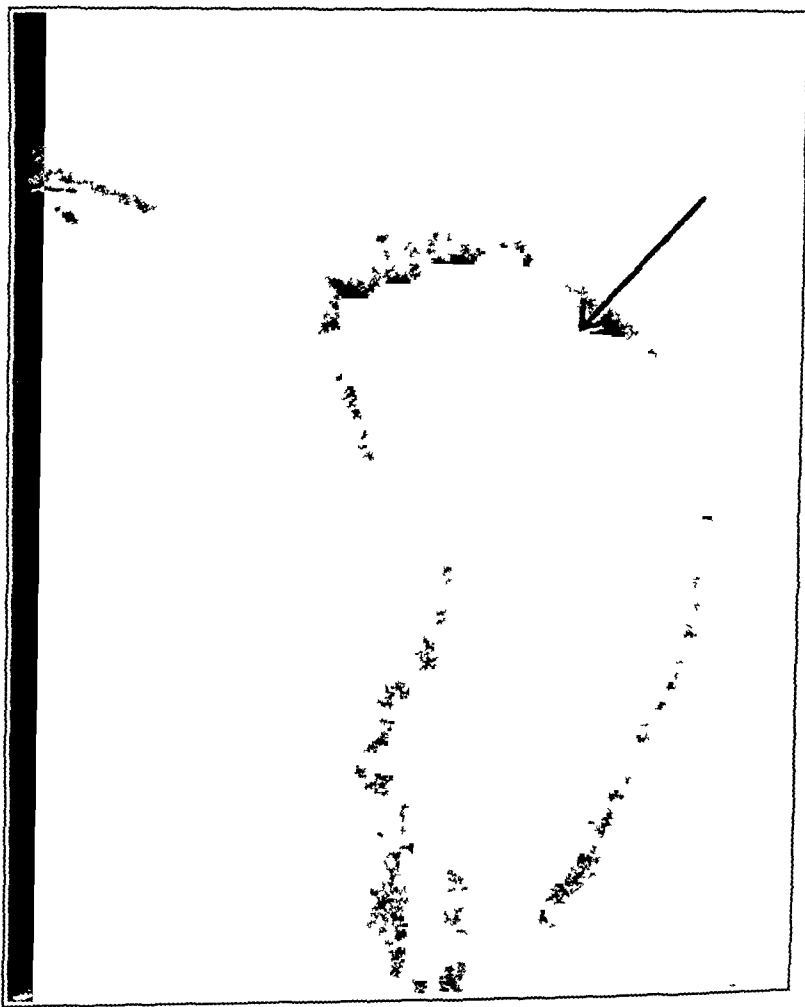


Fig 1—Fracture of the distal end of the left femur at 9 months (the patient's first fracture)

At 4 years and 5 months, he fell from the davenport, alighting on his right arm. The upper third of the right humerus was fractured with comparatively little displacement (Fig 8). Good union was obtained by means of a traction splint, after a triangle in the axilla had failed.

When nearly 5 years old, the boy fell from a cart onto his right shoulder, fracturing the right clavicle about the middle (Fig 9). This break united without deformity, a Velpeau bandage being used. At the same time, roentgeno-

grams were made of both tibias, because of the bowing they presented (Fig 10) This bowing was interpreted by Dr Percy Brown as being due to rickets

When he was nearly 7, the patient fell on the left arm, breaking both bones of the forearm (Fig 11) He was treated in the outpatient department of the Massachusetts General Hospital, and good union was obtained, although marked bowing of both bones remained

At 7 years and 3 months, he fell over backward, his weight falling on his hyperextended palms Swelling appeared over the flexor tendons of the left wrist, and flexion and extension became painful The swelling and tenderness

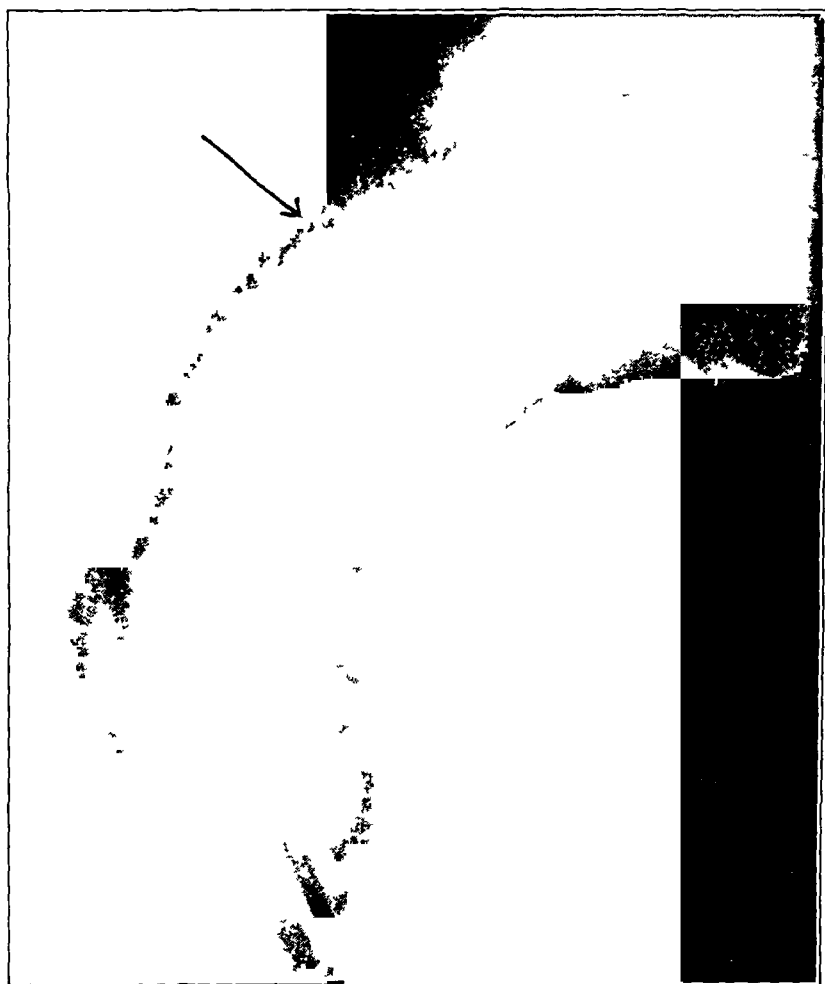


Fig 2—Fracture of the right femur at 1 year and 9 months

disappeared in two or three days, but some ecchymosis remained Slight mobility was detected on palpation, and the roentgen ray demonstrated that a small crack had been opened up at the site of the last radial fracture (Fig 12) This injury was treated with a posterior splint and pads and adhesive straps to correct the bowing, with fairly good results Roentgenograms of all the long bones, the skull and the chest were taken at the same time (Figs 13, 14, 15, 16 and 17) The long bones of the extremities all showed anterolateral



bowing, with marked thickening of the cortex of the diaphysis and relative thinning at the epiphysis. The chest showed nothing remarkable, and the skull showed only moderate thinning.

At 7½ years, the patient tripped over a rug and fell on his right arm. The roentgen ray revealed no evidence of fracture. Nine days later he again fell on the floor at home, breaking the right humerus at about the junction of the middle and upper thirds. The roentgen ray disclosed a clean, right-angled break, with practically no displacement (Fig 18). He walked into the outpatient department that morning. The arm was immobilized with coaptation

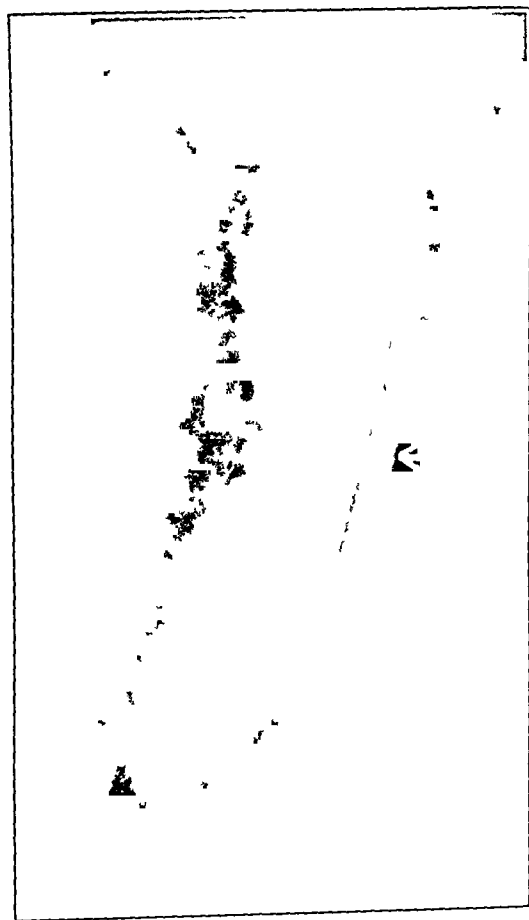


Fig 3—Appearance of the left femur at the time of fracture of the right femur, shown in Figure 2. A cystic area is seen in the lower third.

and an internal angular splint. He was kept under observation until late in the afternoon, and, as there was no evidence of other injury, he was allowed to go home. During the evening he vomited several times and was seen by his local physician, who made a diagnosis of fractured skull, sending him to the hospital. On the way to the hospital, he is said to have died from intracranial hemorrhage. Necropsy was not performed.

*Physical Examination*—At no time did examination reveal anything remarkable about the patient except bowing of the extremities and slight deformities due to the various fractures. As shown in Figure 19, the boy was well proportioned and of about normal size, with a slightly flattened chest and a rather

prominent abdomen. All of the extremities showed moderate outward bowing. The lower, central incisor teeth were absent, and the alveolar process was much thinned out at that point. There was no evidence of the presence of permanent incisors in the alveolar process to replace the missing teeth. The sclerae were of normal color and did not show the dark bluish tint which has often been described in patients with osteopsathyrosis.

*Summary*—The patient was a boy, aged 7½ years, with negative family history, who had sustained multiple long bone fractures, and who died following what was probably a fractured skull. Eleven fractures were demonstrated by the roentgen ray, and there were two other probable fractures which were not

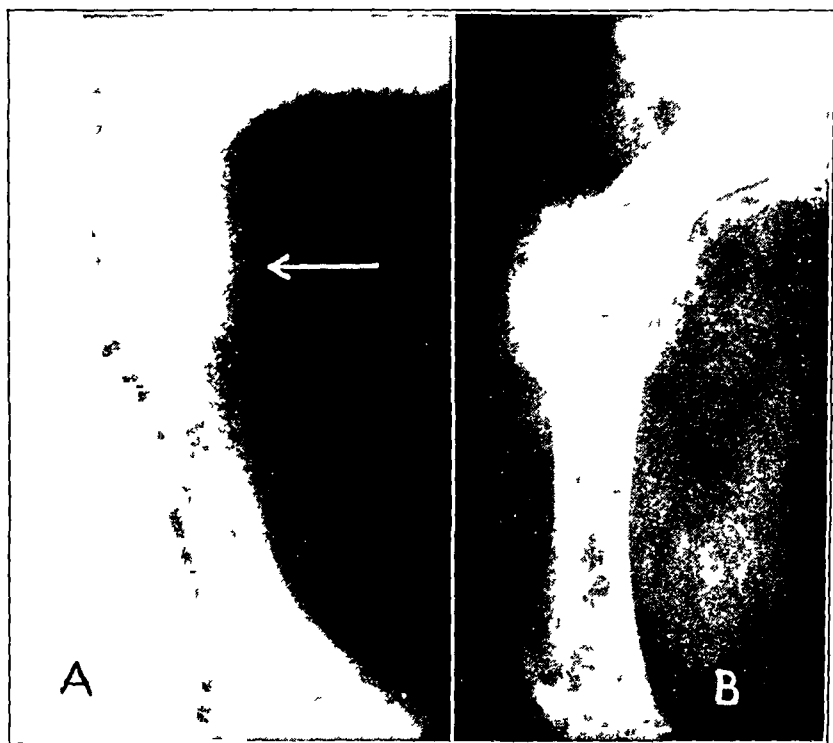


Fig 4—*A*, appearance of femur one month after the fracture shown in Figure 2, showing the excess of callus formation at the site of fracture, *B*, four months after the fracture. The apparent tumor at the site of fracture proved to be callus.

roentgenographed. The fractures were distributed thus: left radius, 4; right humerus, 2 (3?), left femur, 2; right femur, 1; right clavicle, 1; left ulna, 1; and skull, 1 (?).

All of the fractures were the result of comparatively slight trauma, and all, with the exception of those immediately preceding death, united readily. The deformities resulting from fractures were insignificant, but the long bones of all the extremities showed a certain amount of outward bowing from infancy. One of the early fractures showed excessive callus formation, and in one other case a small cystlike rarefaction of the bone was noted.

## TERMINOLOGY

Many names have been applied to this condition which is characterized by congenital bone fragility. Osteopsathyrosis, fragilitas ossium and osteogenesis imperfecta are the terms in common use in the English literature. "Idiopathic osteopsathyrosis" is accepted by most of the

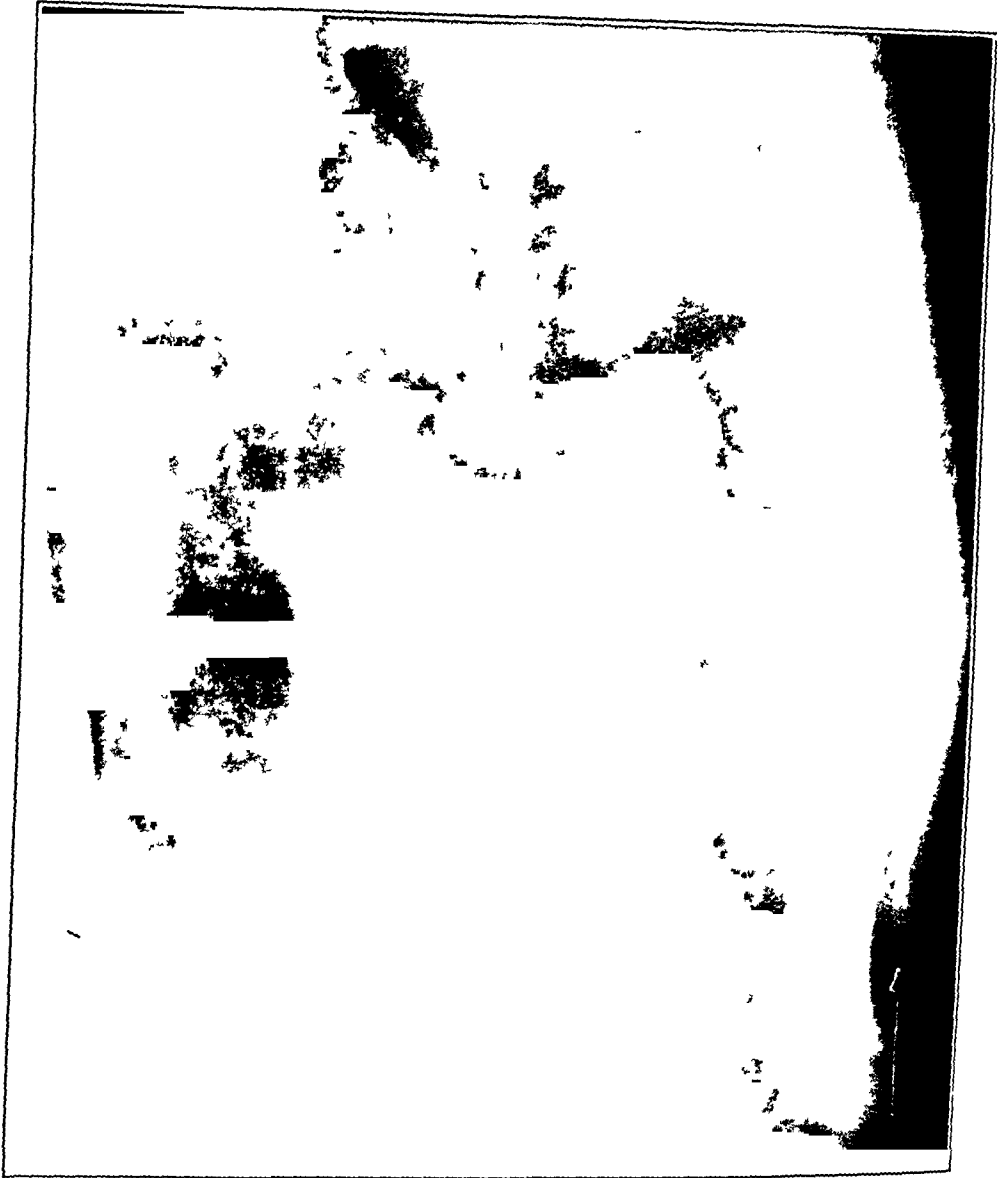


Fig 5—Fracture of the left femur at 2 years and 9 months, shown here by raising of the periosteum. Both femurs show considerable bowing and flaring at the epiphyseal line.

continental writers. It has been pointed out that "fragilitas ossium" accentuates the chief clinical symptom of the disease, while "osteogenesis imperfecta" suggests the etiologic factor of imperfect bone formation.<sup>2</sup> Practically all writers use osteopsathyrosis and osteogenesis imperfecta

synonymously, but Griffith<sup>1</sup> reserves the latter name for cases of multiple intra-uterine fractures, together with imperfect development of membrane bone

#### CLASSIFICATION OF CASES

Nichols<sup>14</sup> divides *fragilitas ossium* into two groups (1) symptomatic fragility, in which fragility is due to one of various known pathologic processes, as rickets, old age, osteomyelitis, tuberculosis,

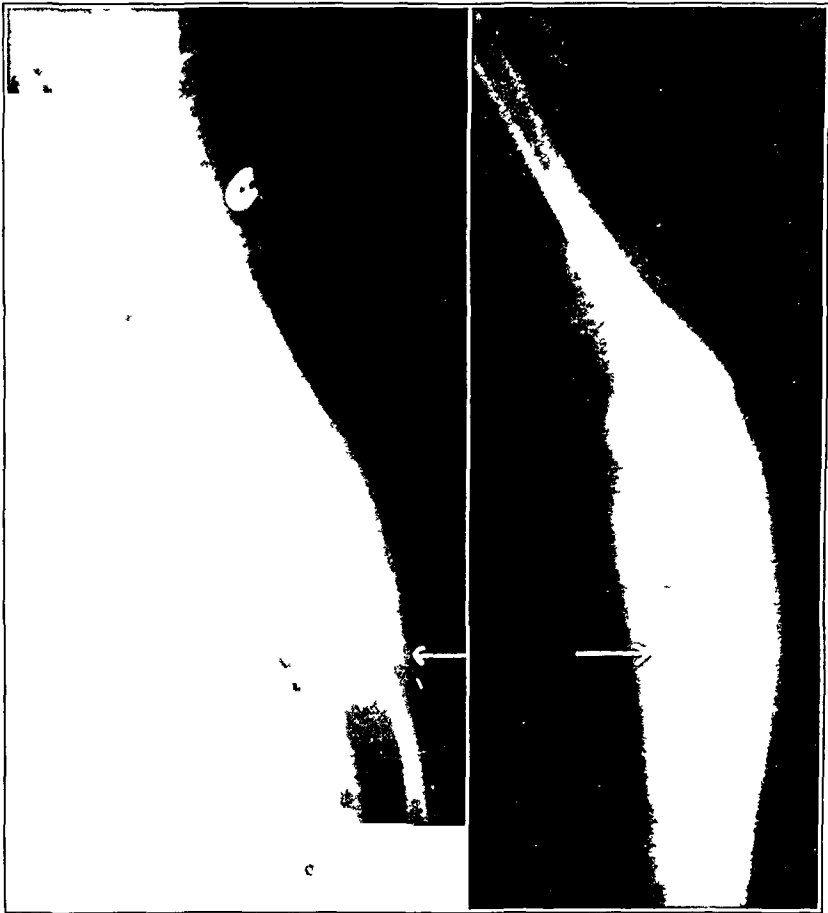


Fig 6—Fracture of the left radius in its upper third at 3 years

tabes, syringomyelia, paralysis, malignant disease, bone cysts or ecchinococcus cysts, and (2) “idiopathic fragility,” which is identical with *osteogenesis imperfecta*. Ostheimer describes two types of cases (1) the fetal type found either at birth or shortly thereafter, with imperfect bone formation and multiple fractures (*imperfect osteogenesis* or *periosteal dysplasia*). Frequently these patients do not

<sup>14</sup> Nichols, E H, in *Keen Surgery Its Principles and Practice*, Philadelphia, W B Saunders Company 2 56, 1914

survive after the first year (2) The congenital type found in infants and children, at birth or later, with fractures recurring often until puberty or even adult life, associated with similar bone changes (idiopathic osteopsathyrosis) These patients, with care, will survive but are often badly crippled Locke<sup>15</sup> adds a third, the adult form, encountered as an idiopathic fragility of the bones after childhood

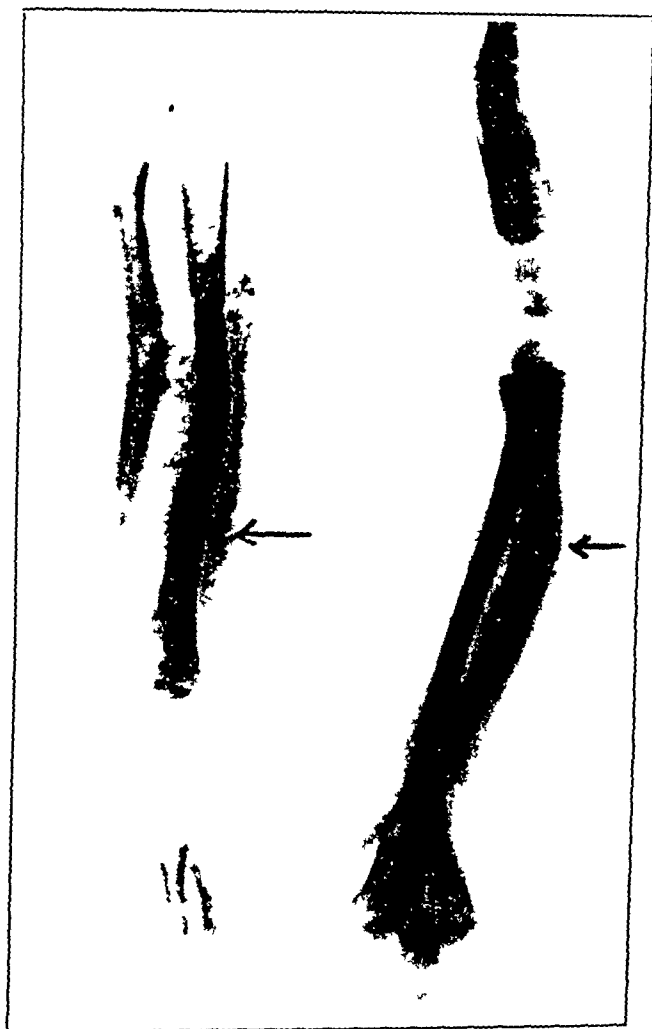


Fig 7—Fracture of the left radius in its lower third at 4 years

#### ETIOLOGY

No definite etiology for osteopsathyrosis has been determined It occurs about equally in males and females The hereditary factor has been recognized by many writers,<sup>16</sup> and the incidence of osteopsathy-

15 Locke, E A Oxford Medicine, New York, Oxford University Press 4 452, 1921

16 Conard, H S, and Davenport, C B Hereditary Fragility of Bone, Bull 14, Eugenics Record Office, Cold Spring Harbor, N Y, November, 1915 (Includes a complete bibliography)

rosis in persons with blue sclerae is sufficiently high to suggest that there is a definite relation between the two conditions

The principal theories advanced as to the etiology are (1) The disease is an affection of some central organ (osteotrophic organ) which furnishes some substance necessary for the normal formation and nutrition of bones,<sup>6</sup> (2) the disease is of nervous origin,<sup>17</sup> and (3) it is due to some disturbance of nutrition affecting the entire bone system during fetal life<sup>18</sup>



Fig 8—Fracture of the right humerus at 4 years and 5 months

#### PATHOLOGY

The disease apparently affects only the bones, as no constant pathologic condition has been found elsewhere in the body

Growth of the bones in length usually proceeds normally, but the bones may appear to be much shortened because of bowing and angulation resulting from fractures. There is no constant gross deformity

17 Biggs, M H Univ Penn M Bull **15** 488, 1902-1903

18 Harbitz, F Beitr z path Anat u z allg Path **30** 605, 1901

In some cases, the bones have been described as being thin and delicate, but in many cases (as in the case described herewith), the bones appear to be proportioned normally. The extent of deformity usually depends on the number of fractures previously sustained, although (as cited above) there is often an intrinsic bowing of the long bones, entirely independent of traumatic deformities. This bowing is usually not so pronounced as that of rickets, and is confined to the diaphysis, in contrast to the epiphyseal deformities in rickets.

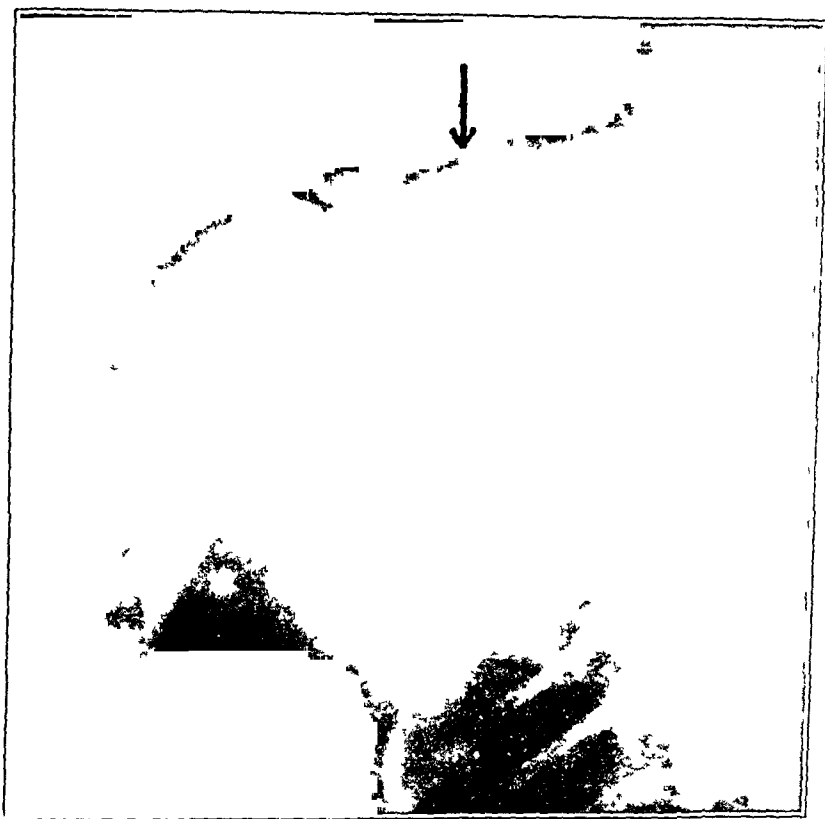


Fig 9—Fracture of the right clavicle at 5 years

The skull is usually normal in size and shape in the older cases. In the early, fetal cases, the skull may be only a membranous sac with islands of calcification.

Microscopically, the bone usually shows a cortex which is thin and friable with occasional islands of cartilage. Trabeculae are often imperfectly formed or absent. Nichols<sup>14</sup> says that instead of osteoblasts depositing new bone on a cartilaginous matrix, the trabeculae are formed by calcification of cartilage cells. The dense bone formed is nonlaminated or imperfectly laminated, with no haversian canals but with large marrow spaces in which there are few trabeculae. The formation of periosteal bone is also abnormal and incomplete. Several writers have called attention to the fact that in this disease there is

increased absorption of bone but very scant bone proliferation. There is a difference of opinion concerning the relative amount of calcium salts present, it not being definitely determined that there is a lack of calcium in patients with osteopsathyrosis.



Fig 10—Marked anterior bowing and thickening of the midportion of the diaphyses of the bones of the lower leg at the time of fracture of the humerus, shown in Figure 9

#### SYMPTOMATOLOGY

Aside from the tendency toward frequent fractures, there are practically no constant symptoms.

In some of the earlier cases, the appearance of the patients conforms more or less to type. They have a relatively large head, small chest,



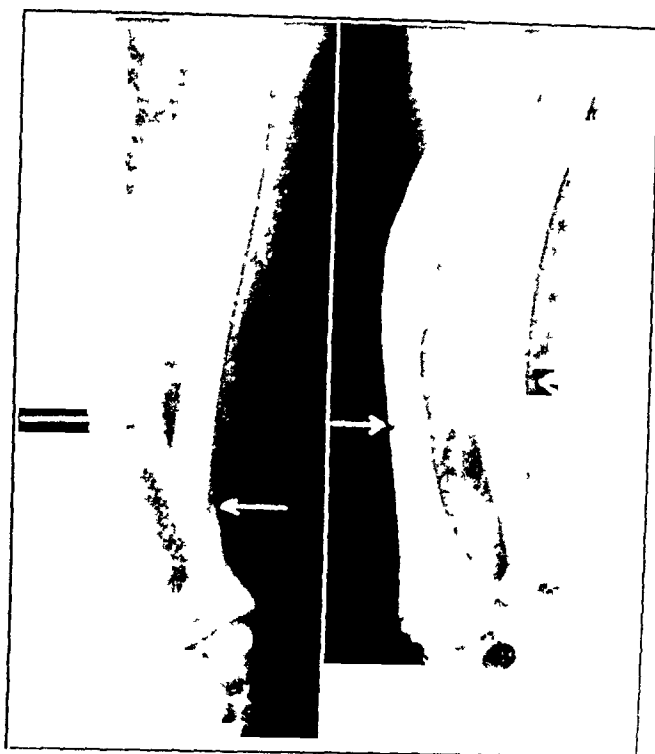


Fig 11—Fracture of both bones of the left forearm at 7 years

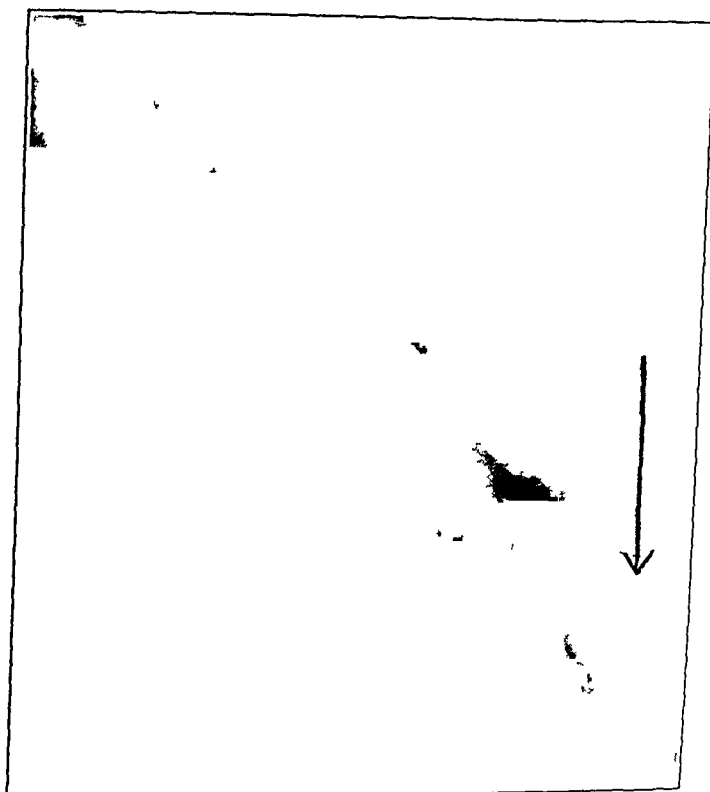


Fig 12—Refracture of the left radius at 7 years and 3 months, at the site of the previous fracture

and a protuberant abdomen. The later cases, however, may show no recognizable peculiarities of form.

As has already been mentioned, in some patients there is a dark blue tint in the sclerae, which is said to be due to deficiency of the sclerotic fibrous tissue, allowing the pigment of the choroid to show through.

*Character of the Fractures*—As the name suggests, the most characteristic symptom of the disease is the extreme brittleness of the bones

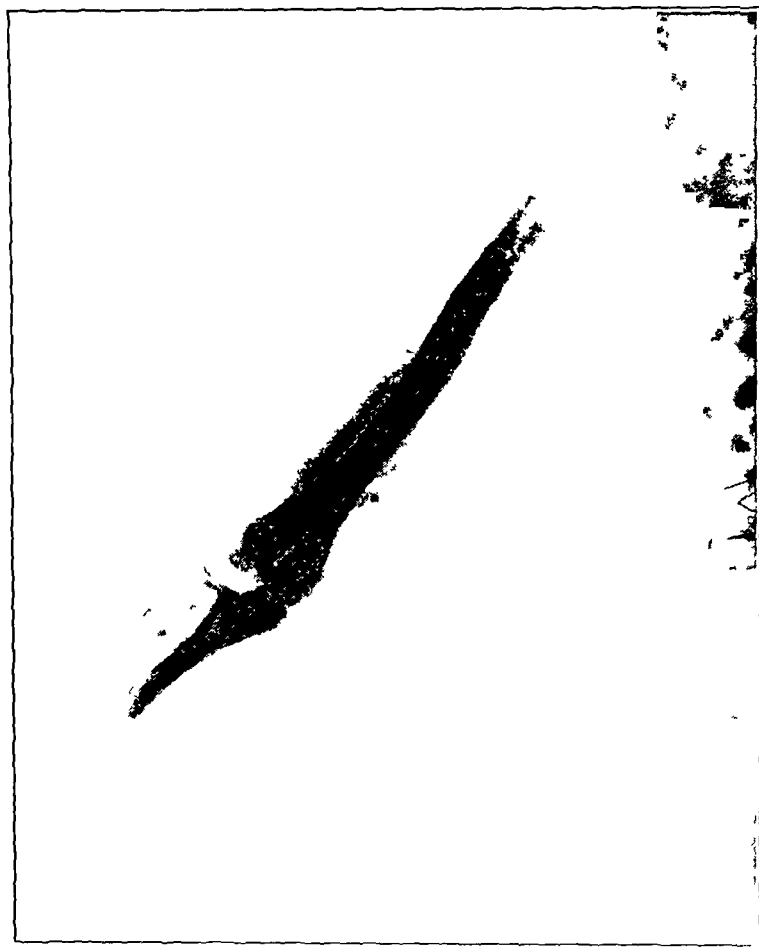


Fig. 13—Characteristic deformity of the bones of the arm, three months before the patient's death.

and the ease with which fractures are sustained. The trauma is usually slight, and very often the signs of fracture are meager. Instances have been cited in which even the most careful handling of diseased infants or children caused fractures, and in other cases a mere handshake has been enough to break the forearm. Very little pain, tenderness or swelling is attendant on these fractures, mobility or deformity often being the only sign found. Frequently the child will show nothing

more than unwillingness to use the affected arm or leg. The tendency to fracture is bilateral, and both sides of the body are usually affected sooner or later. The long bones of the extremities, the clavicles and the ribs are the most common seats of fracture, but the other bones of the

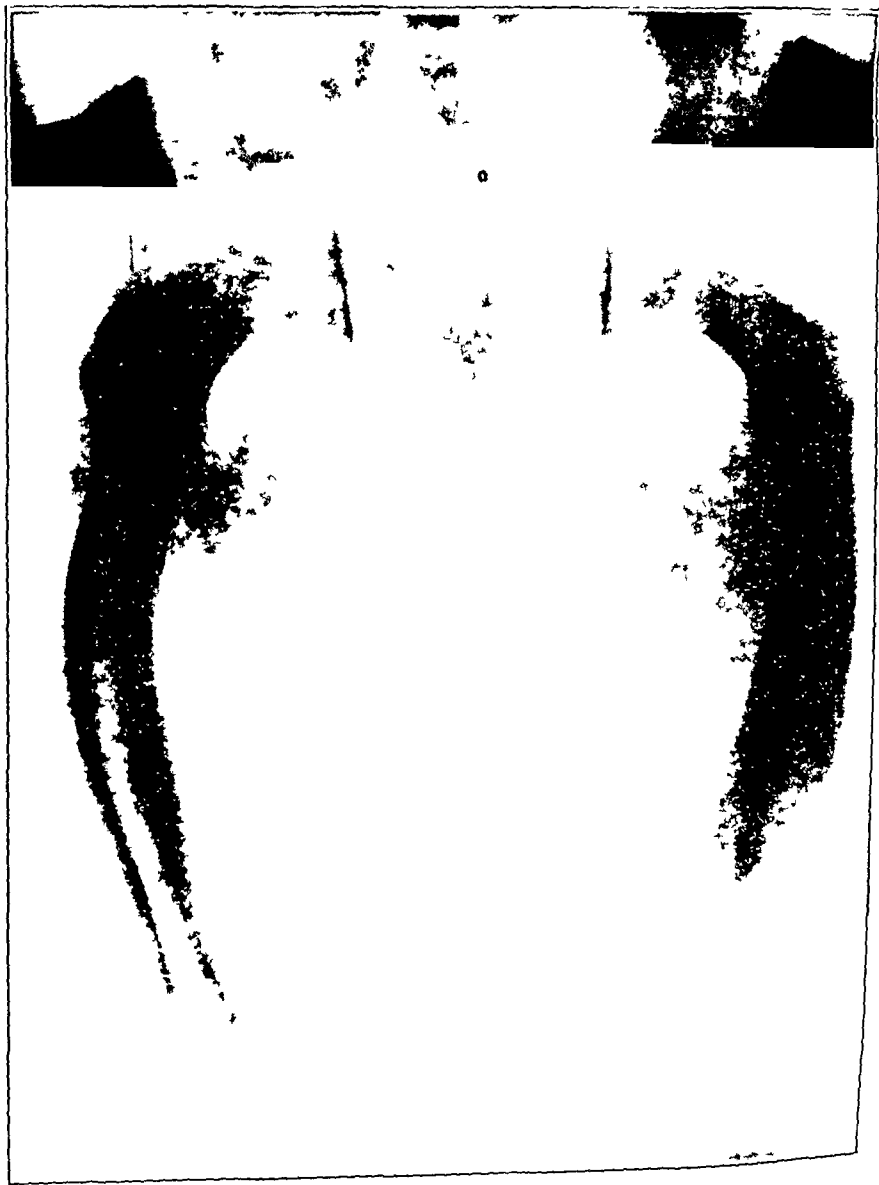


Fig 14—Characteristic deformity of the femurs, three months before the patient's death

body are occasionally involved. The femur is the one bone most commonly broken in osteopetrosis (Locke). Fracture of the skull is comparatively rare.

Kienbock states that the periosteum is rarely ruptured. The callus forms in the usual way and is variable in amount. It is generally said

that these fractures unite more readily than those in normal bone, but Kienbock asserts that the healing may not be complete for several months. In support of his contention may be mentioned the fact that refracture occasionally occurs at the site of previous injury, several months after union is thought to be complete. Such an instance is cited in the case described herewith. Certainly most of the fractures in this case were followed by apparently firm union in shorter time than that

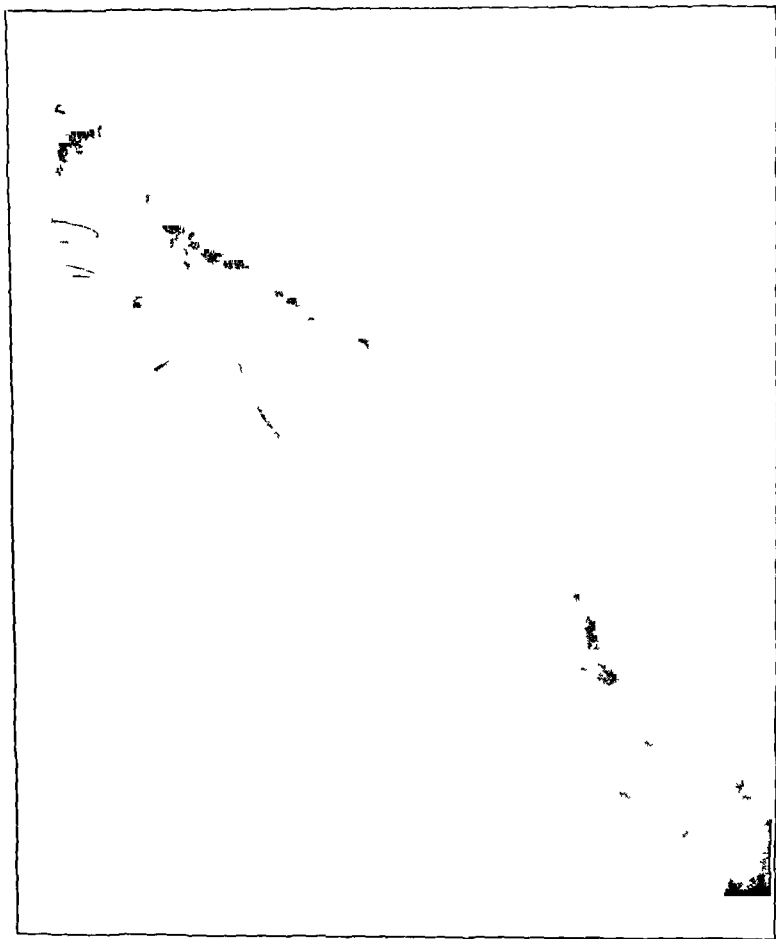


Fig 15—Characteristic deformity of the bones of the leg, three months before the patient's death

required for most normal bones. Kienbock also asserts that the callus may be considerably hypertrophied, an instance of which peculiarity was noted above, following one of the early femur fractures (Fig 4 B).

The number of fractures varies greatly, but few patients have less than ten. Terry<sup>19</sup> reports the case of a man, aged 42, with more than

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<sup>19</sup> Terry, W. I. Hereditary Osteopsathyrosis, *Ann Surg* 68 231 (Aug) 1918

sixty fractures. Mixsell records the case of Chaussier with 113 fractures. According to Emerson,<sup>20</sup> the tendency to fragility is lost if the patient lives to be 30, but he mentions one case in which the disease continued to the seventieth year.

*Röntgen-Ray Appearances*—Locke<sup>17</sup> has admirably summarized the roentgen-ray findings noted by various authors, as follows: “(1) a high degree of osteoporosis uniformly affecting the entire skeleton,



Fig. 16—Appearance of the chest of the patient, three months before his death.

the variations in density giving a mottled appearance, (2) marked deformities of the long bones of the extremities, usually of the angular type, due to fractures, rarely also some actual bowing, (3) apparently normal size and shape of bones, except as altered by fractures and resulting callus formation, (4) often excess callus formation.

<sup>20</sup> Emerson, C. P., in Osler and McCrea. System of Medicine, New York Oxford University Press 6 723, 1909.

with variable degree of calcification. A transverse line of decalcification is often seen at the point of previous fracture, (5) the epiphyseal line is straight, cartilage is always thin, (6) a very faint shadow is given by all the bones, frequently scarcely more dense than that of the surrounding soft parts, (7) the cortex is thin, irregular and deficient in salts, (8) the spongiosa of both epiphysis and diaphysis is extremely faint with entire absence of normal markings, (9) the medullary cavity

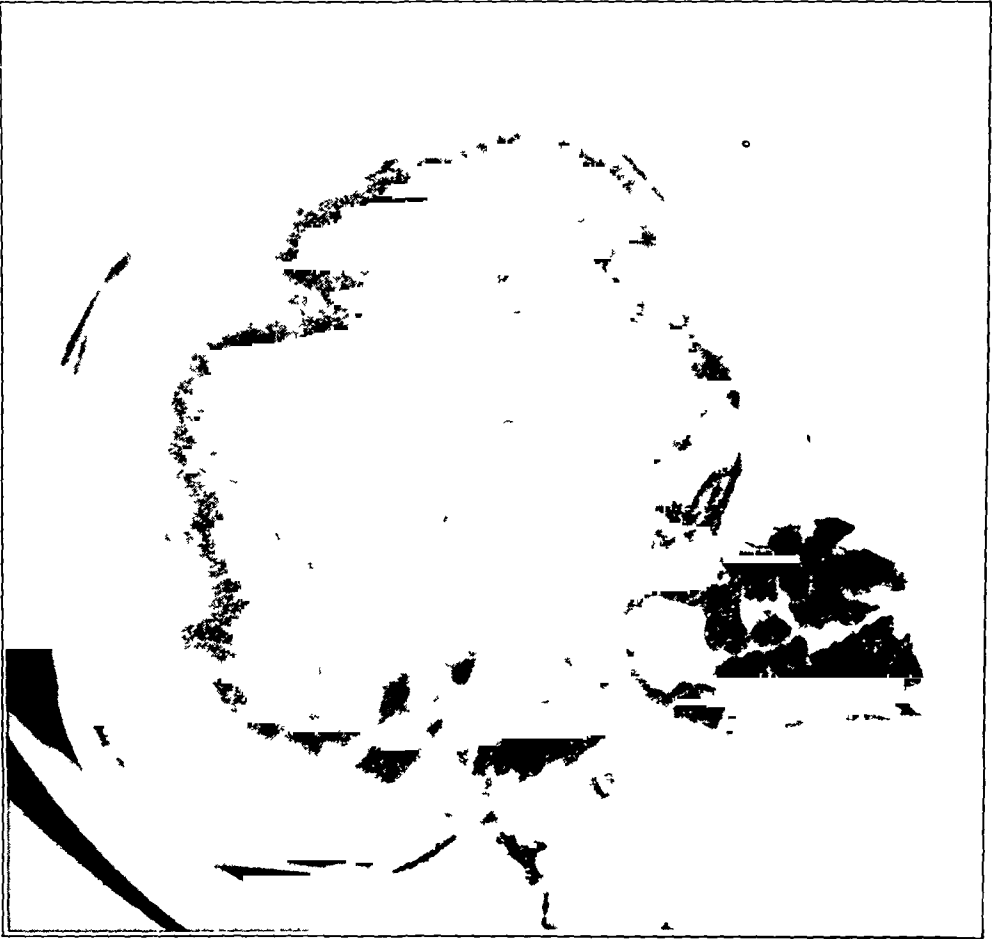


Fig 17—Appearance of the skull of the patient, three months before his death

is very irregular in outline and dilated." These changes are considerably less marked in some of the milder cases, such as the one described above.

*Metabolism*—Several interesting metabolic studies on patients with osteopsathyrosis have been made within the last few years. While these studies have not been conclusive they have suggested that calcium

metabolism may have some bearing on this type of bone fragility, as well as on the deformities of rickets. They have also suggested a method of treatment which may prove to be helpful.

Bookman<sup>21</sup> reported studies on a man, aged 27, with osteopsathyrosis, who had a healed fracture, five weeks before the time of the experiment. He found in this patient a markedly negative calcium balance (loss of 0.019 gm of calcium monoxid per kilogram of body

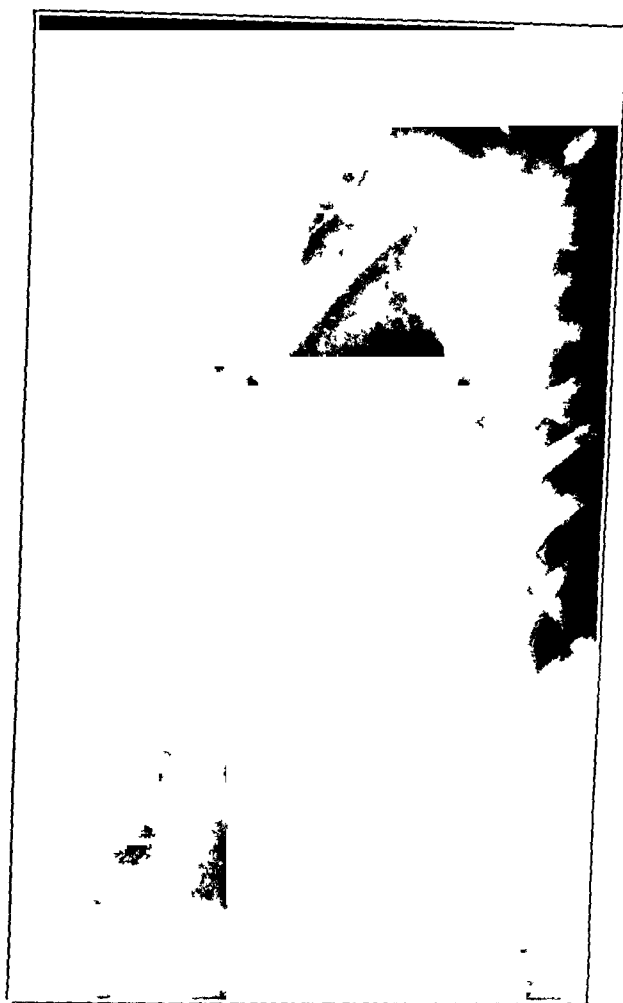


Fig. 18—Fracture of the right humerus at 7 years and 6 months. On comparing this illustration with Figure 8, it will be noted that the cortex of the diaphysis is relatively thinner than it was at the time the earlier roentgenogram was taken.

weight), and likens this to similar findings in osteomalacia. The negative balance is explained by the fact that in both conditions calcium from the already formed bone is being liberated and thrown out of the system.

<sup>21</sup> Bookman, A. The Metabolism in a Case of Idiopathic Osteopsathyrosis, *Arch. Int. Med.* 8:675 (Nov.) 1911.

Schwarz and Bass<sup>3</sup> studied the metabolism of a 7 months old infant with osteogenesis imperfecta, who had had no fractures subsequent to the fourth day after birth. They found a practically normal, or positive, calcium balance (with retention of 0.109 gm.)



Fig 19—Appearance of patient at 7 years and 3 months

Bamberg and Huldshinsky's<sup>4</sup> case showed a variation from a loss of 0.019 to a gain of 0.136 gm., the latter figure being obtained while the patient was under treatment with cod liver oil and phosphorus.

Bookman,<sup>5</sup> in his studies on a 3 months old infant with osteogenesis imperfecta, also found a low calcium retention, which, however, varied with the course of the disease. He also found that the deficient reten-



tion of calcium was favorably influenced by the administration of cod liver oil and phosphorus, and still more by calcium lactate. He believes that the similar results obtained in rickets suggest an etiologic relationship to osteopsathyrosis.

Ruggen<sup>10</sup> studied the metabolism in a girl of 13, with a history of twelve fractures. He found that she had a daily high deficit in the phosphorus, calcium and magnesium balance. This balance was improved for a short time by the administration of thymus and suprarenal extracts, but gradually the condition returned to its original status within a few months.

#### PROGNOSIS

The outlook in cases of osteopsathyrosis is poor, in spite of the fact that a few patients have grown to adult life, apparently overcoming the bone fragility from which they suffered in earlier years. Most of the patients that survive are deformed by earlier fractures. Few fractures occur after the patient is in the early twenties, and after that time the prognosis is fairly good. Below that age, however, the mortality is high. The mortality is almost 100 per cent in the fetal type, the majority dying in utero.

#### DIAGNOSIS

The diagnosis is usually perfectly clear, because there is no other congenital disease in which multiple fractures occur. Rickets and syphilis occasionally cause fractures in young children, but rarely more than two or three fractures occur in the same person as a result of these affections.

#### TREATMENT

The fractures are treated in the usual way, great care being taken to prevent distressing deformities, by preserving good alignment.

The metabolic studies already mentioned would point to the efficacy of cod liver oil and phosphorus, and in some cases they have seemed beneficial. Hess<sup>8</sup> uses a dose of 4 c c, twice daily, of either of the following preparations: phosphorus, 0.01 gm, and cod liver oil, 60 c c, or pure tribasic calcium phosphate, 6 gm, and cod liver oil, 60 c c. Czerny<sup>22</sup> reports benefit from the use of 100 gm daily of raw carrot juice, on the theory that osteopsathyrosis is an avitaminosis.

Care of the patient to prevent fractures is the most important single factor in the treatment of osteopsathyrosis.

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<sup>22</sup> Czerny, A. *Berl klin Wchnschr* 61 310, 1919, *Deutsch med Wchnschr* 45 259, 289 (March 6) 1919.

# THE DELBET WALKING PLASTER FOR TREATMENT OF DELAYED UNION IN FRACTURES OF BOTH BONES OF THE LEG

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Delayed union is a common complication in fractures of both bones of the leg, especially those in the lower third. The term will be here used to describe those cases in which there is movement between the fragments and tenderness at the site of fracture, and in which the roentgenograms reveal open medullary cavities and little or no callus formation. Pseudarthrosis has not developed in these cases.

The treatment for delayed union has very generally been direct fixation of the broken ends by metal inserts or bone grafts. These methods may succeed, but in too many instances they have failed because a long period of immobilization has produced atrophic and poorly nourished fragments—conditions unfavorable to the production of callus or the proliferation of a bone graft. The patient has also been subjected to all the risks of a major operation, including the danger of sepsis. The clinical picture of these cases is characteristic, a withered limb and stiffness of the joints—both evidence of poor circulation and deficient nutrition.

The reverse of this picture may be produced by the substitution of a method that not only is simpler but also embodies a principle fundamental to the growth of bone—provision for the mechanical stimulation of the fragments.

Experience in the treatment of these cases has shown that this stimulus may be best supplied by active use of the limb in weight bearing, which not only improves the impaired circulation but stimulates the osteoblasts, with resulting production of callus. To allow such use of the limb in weight bearing, some apparatus is necessary which will prevent further displacement of the fragments and at the same time permit free circulation in the limb and active use of the muscles and joints. The Delbet ambulatory splint has proved a simple and efficient appliance in meeting these requirements.<sup>1</sup>

## DESCRIPTION OF THE DELBET AMBULATORY SPLINT

The apparatus consists of lateral, molded plaster-of-Paris splints reaching from the knee to the junction of the skin of the sole with that

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<sup>1</sup> Mocquot, Pierre, and Caraven, J. La marche directe dans les fractures de jambe. *Rev de chir* 40 601, 1909

of the upper part of the foot. Two molded plaster bands are passed about the lateral splints, one just below the knee, the other just above the malleoli. These bands bear, and cause the lateral splints to bear, against the tuberosity of the tibia and the head of the fibula above and against the malleoli below, thus preserving the length of the leg (Fig 1)

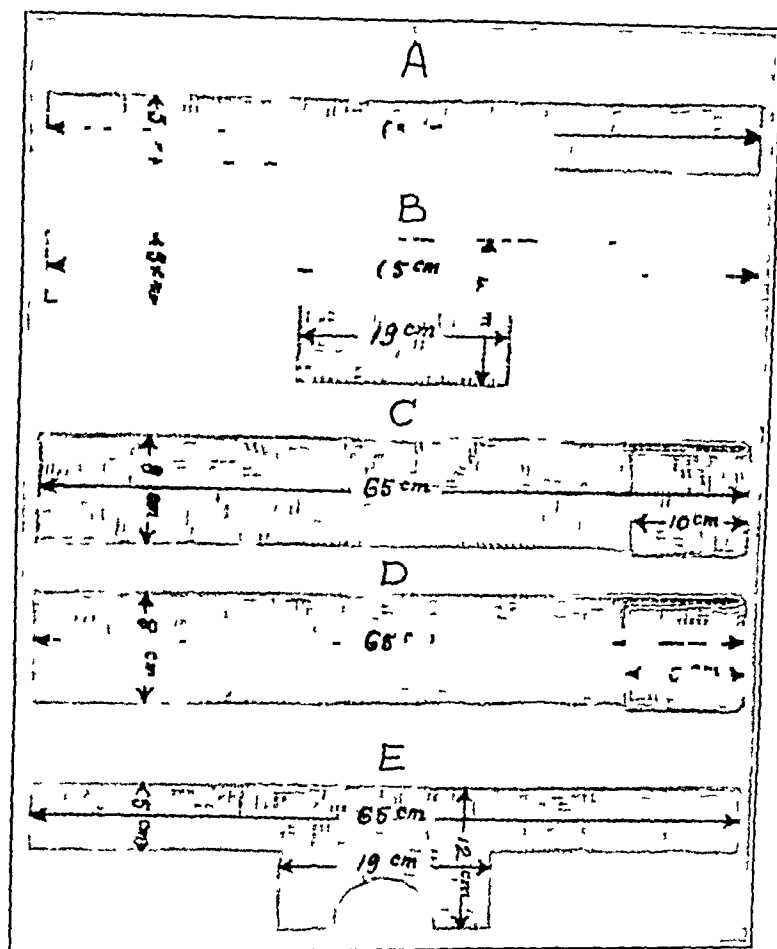


Fig 1—Method of cutting strips of crinoline to make the plaster bands for the Delbet ambulatory splint for fracture of the tibia and fibula. *A*, upper band, *B*, lower malleolar band, *C* and *D*, lateral bands with folds 10 cm long at the inferior extremity, and *E*, lower band for the malleoli, with notch cut in the heel piece for the heel (from Leriche)

#### APPLICATION OF THE APPARATUS

The apparatus is applied directly to the shaved and greased skin. The two lateral molds are applied to the leg and held by assistants while the operator anchors them with the circular cuffs, one about the tuberosity of the tibia and the upper end of the fibula, the other just above the malleoli. The plaster is then carefully molded to the leg, especially about the tuberosity of the tibia and the malleoli. It is very essential

that the plaster be smooth in order to prevent irritation of the skin and the formation of pressure sores. A snug bandage is applied until the plaster has set. Figures 2 and 3 are front and side views of the Delbet splint applied.

At first the patient is allowed to walk using crutches, permitting only partial weight bearing. As soon as he has become accustomed

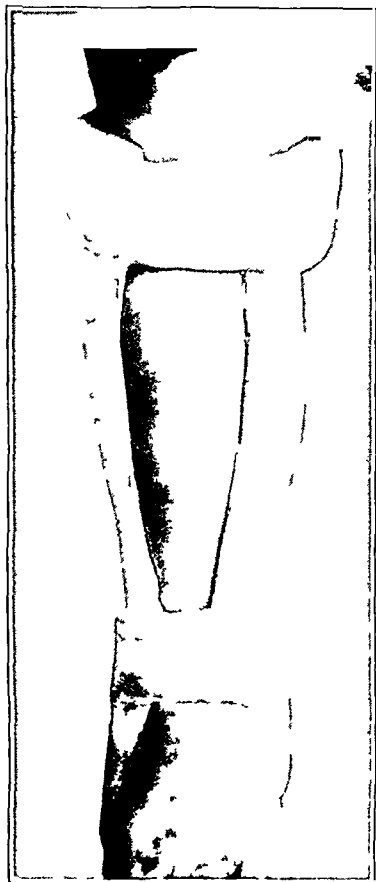


Figure 2

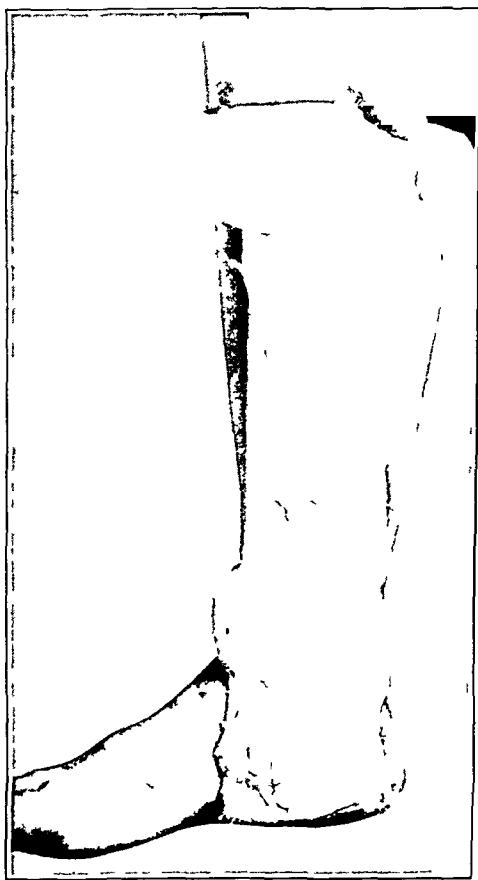


Figure 3

Fig 2—Anterior view of Delbet walking plaster

Fig 3—Lateral view of Delbet walking plaster

to the apparatus, the crutches are discarded and a cane substituted. In from a few days to a week, the patient is walking with no other support than that provided by the splint. It is essential that the patient be under close observation for at least the first few weeks of treatment to guard against undue pressure on the malleoli or tuberosities. It is a good practice to change the splint once a month in order to care for the skin and to determine the position of the fragments and the amount of union. Roentgenograms are taken once in six weeks to observe the callus production.

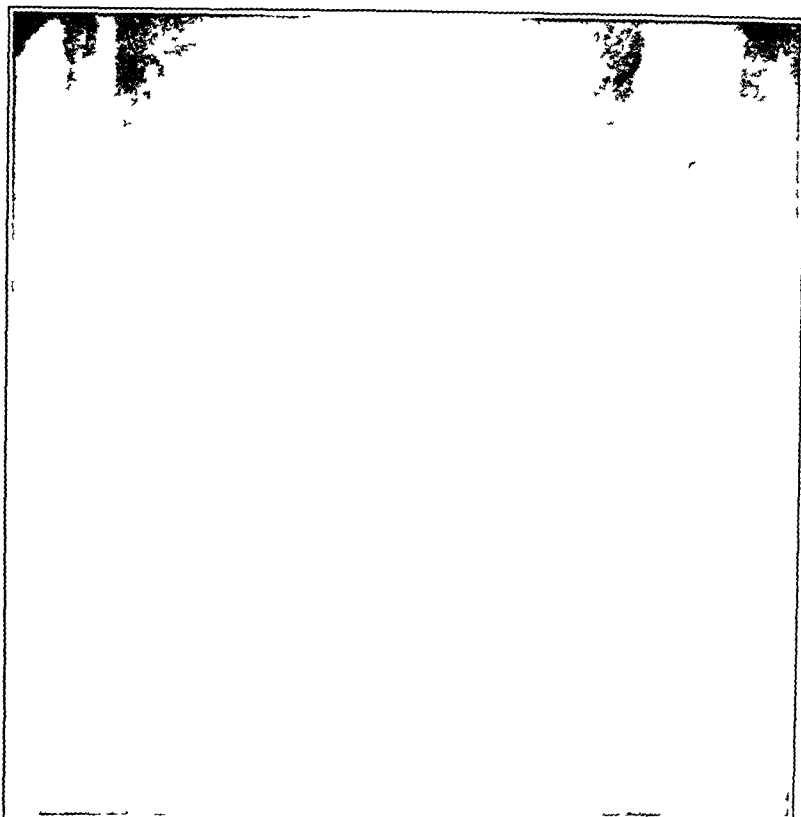


Fig 4 (Case 1) —Ununited fracture of four months' duration, showing no callus

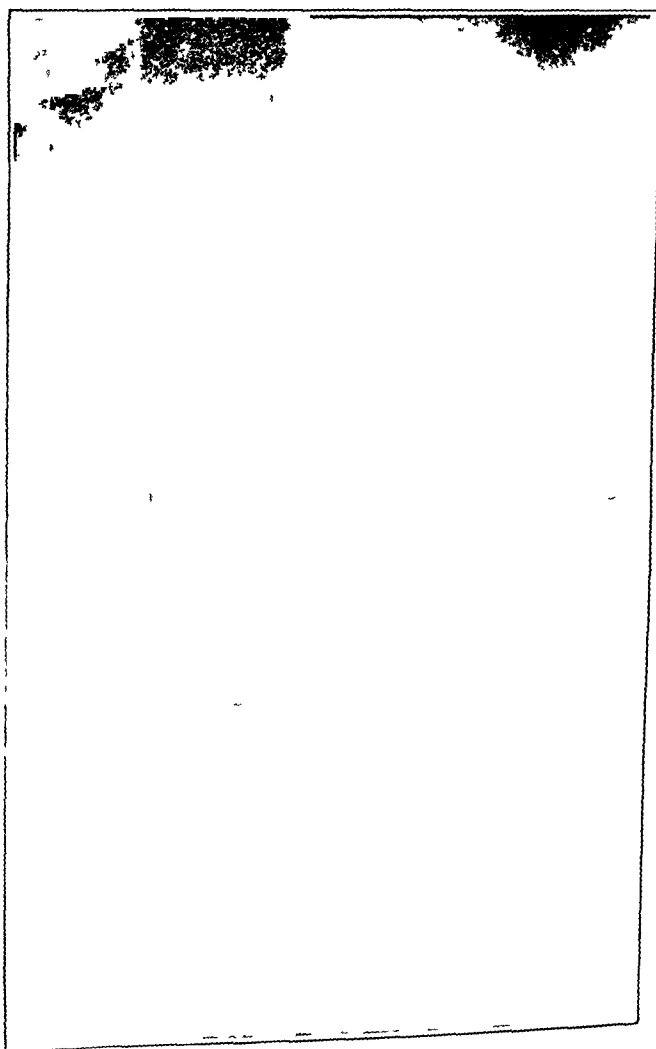


Fig 5 (Case 1) —Marked increase in callus, three months after application of Delbet splint

The results obtained have convinced us that cases of ununited fracture of both bones of the leg of several months' standing should be treated by some form of weight-bearing appliance, preferably the Delbet splint. It has enabled us to avoid operations in a number of instances. Case 1 is a good example of a very satisfactory result. This patient entered the hospital with an ununited fracture of both bones of the leg, of four months' duration. Previous treatment had been reduction

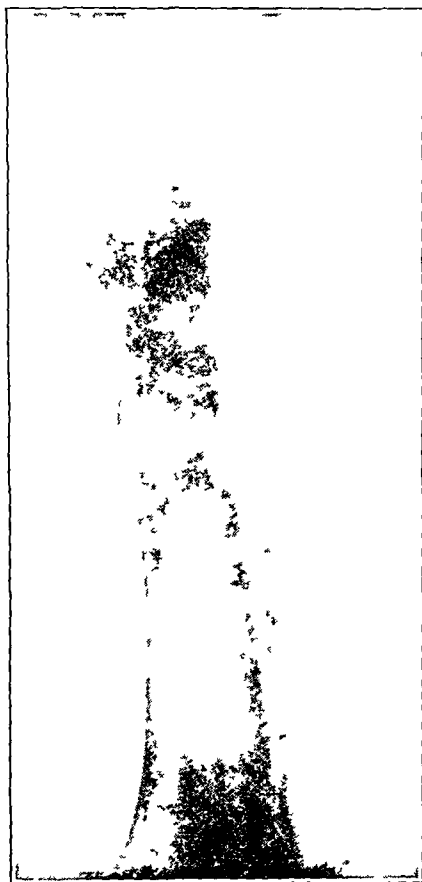


Fig 6 (Case 1) —End-result, showing consolidation of callus

followed by fixation in a plaster-of-Paris cast for a period of three months. The position of the fragments and the amount of callus, four months after injury, are shown in Figure 4. The leg was put in the Delbet splint for a period of three months, when union was firm. The amount of callus is shown in Figure 5. Figure 6, taken five months later, shows complete consolidation of the callus. Four months after admission, the patient was working as a hospital orderly without a splint and with free motion in the knee and ankle joints.

That this method has proved successful when operation with plating has failed is illustrated by Case 2 (Figs 7, 8, 9 and 10) Three months after application of the plate at another hospital, there was no union Two and one-half months after the application of the Delbet splint, union was firm and the roentgenograms revealed a definite production of callus

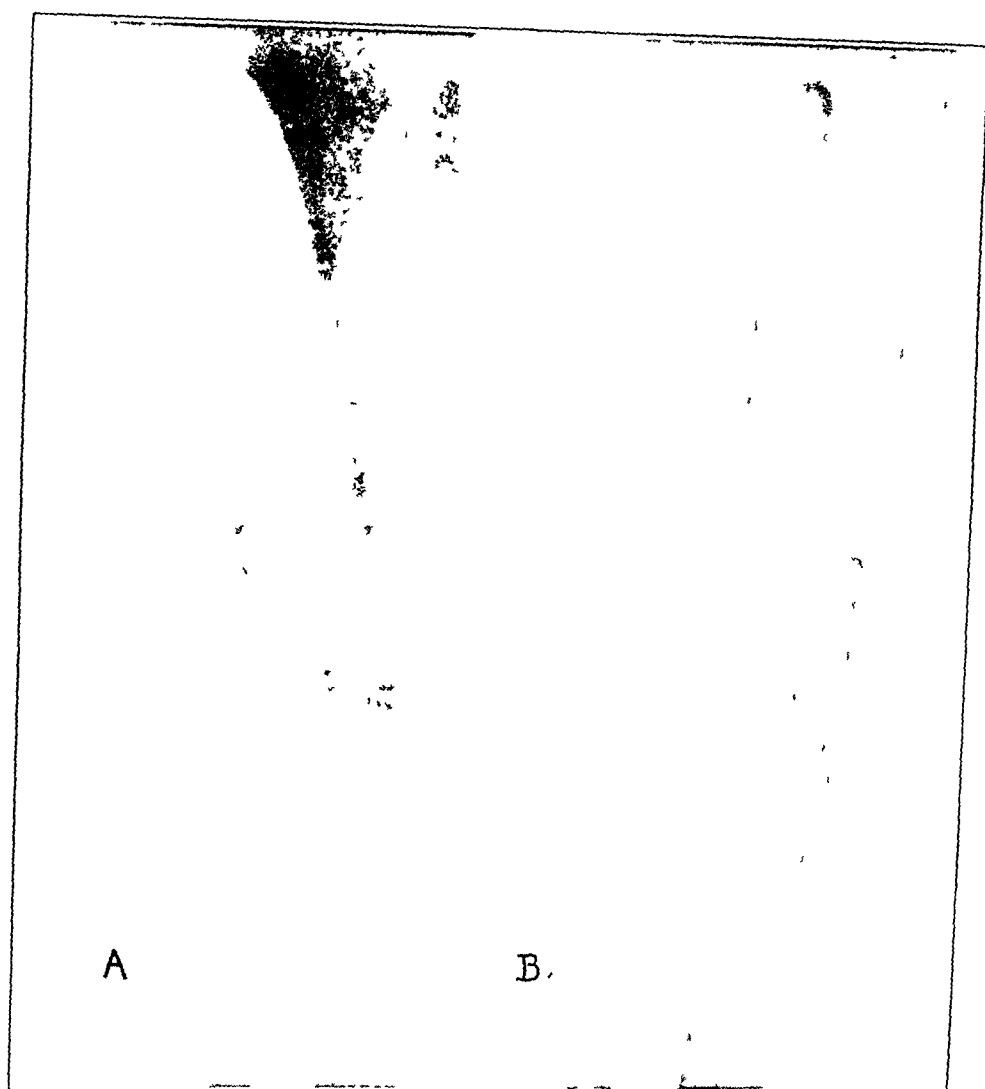


Fig 7 (Case 2)—*A*, fracture with overriding of fragments, *B*, fracture, three months after operation, showing no callus

Satisfactory results have also been obtained in cases in which operations had been performed either with or without bone grafts, the operation being followed by sepsis and osteomyelitis Cases 3 and 4 are examples of this type It is well known that mild infection of bone will often stimulate callus formation, but in these cases, two months of fixation in a satisfactory position failed to produce union The use of

the Delbet splint for a period of from four to five months resulted in union. The progressive formation of callus is shown in Figure 11 (Case 3) and in Figures 12, 13 and 14 (Case 4)

#### REPORT OF CASES

CASE 1—A teamster, aged 45, April 5, 1920, was struck by a log, causing fracture of both bones of the right leg at the middle third. The treatment consisted of reduction of the fracture and immobilization for a period of three

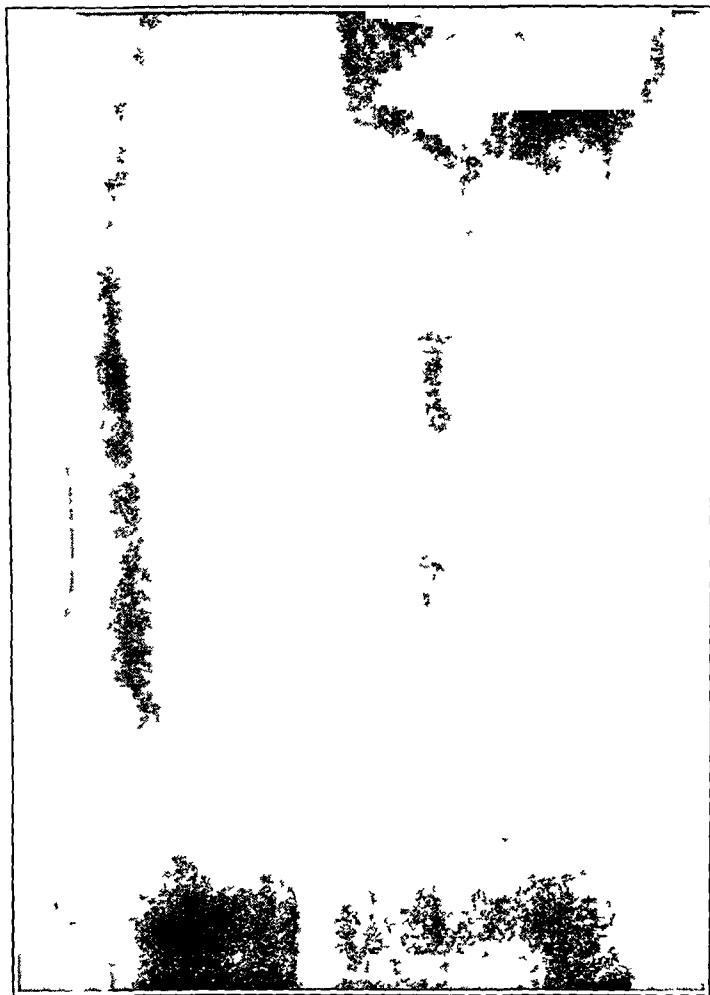


Fig 8 (Case 2)—Callus forming, one month after application of Delbet splint

months. At the end of that time he was unable to bear weight on the leg because of weakness and pain at the site of fracture. He entered the University Hospital, Aug 4, 1920.

Examination revealed an ununited fracture of both bones at the middle third of the leg, motion with pain at the site of fracture of the tibia and three-fourths inch (19 cm) shortening. The ankle joint was swollen and motion was limited. He was unable to bear weight on the leg because of pain. The Wassermann reaction was negative. The roentgenogram (Fig 4),



taken Aug 5, 1920, demonstrated an oblique fracture of the tibia with displacement and overriding of the fragments, double fracture of the fibula and little callus formation

Aug 9, 1920, a Delbet splint was applied and weight bearing begun. Limited motion of the ankle joint caused some pain on walking.

Sept 21, 1920, the Delbet splint was removed. There was only slight motion between the fragments. A new Delbet splint was applied. The patient walked without other support.

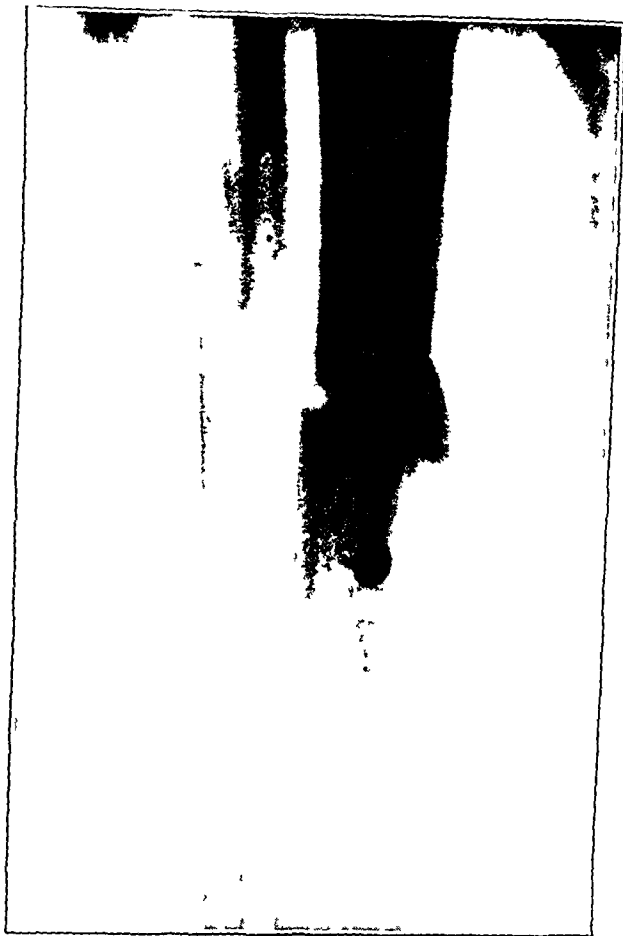


Fig 9 (Case 2) —Increase in callus, two months after application of Delbet splint.

Nov 9, 1920, union was firm. Figure 5 shows the very decided increase in the amount of callus. The patient is working as an orderly in the hospital with no supportive apparatus. The ankle joint is only slightly limited in motion. A roentgenogram (Fig 6), taken April 22, 1921, showed complete consolidation of the callus.

CASE 2 —A lumberman, aged 48, April 21, 1920, sustained a fracture of both bones of the leg at the junction of the upper and middle thirds. Figure 7A shows the position of the bones, with marked overriding of the fragments. Operation was performed April 30, 1920. The fragments of the tibia were cut off, the ends apposed and a Lane plate applied. I saw the patient first, July 16, 1920. He was wearing a plaster cast and using crutches without weight.

bearing Examination revealed good alinement of the fragments, tenderness and motion, with pain at the site of fracture The roentgenogram (Fig 7 B), taken July 16, 1920, revealed perfect approximation of the fragments, but no evidence of union

Aug 15, 1920, a Delbet splint was applied

Sept 18, 1920, the Delbet splint was removed Figure 8 shows the increase in callus formation

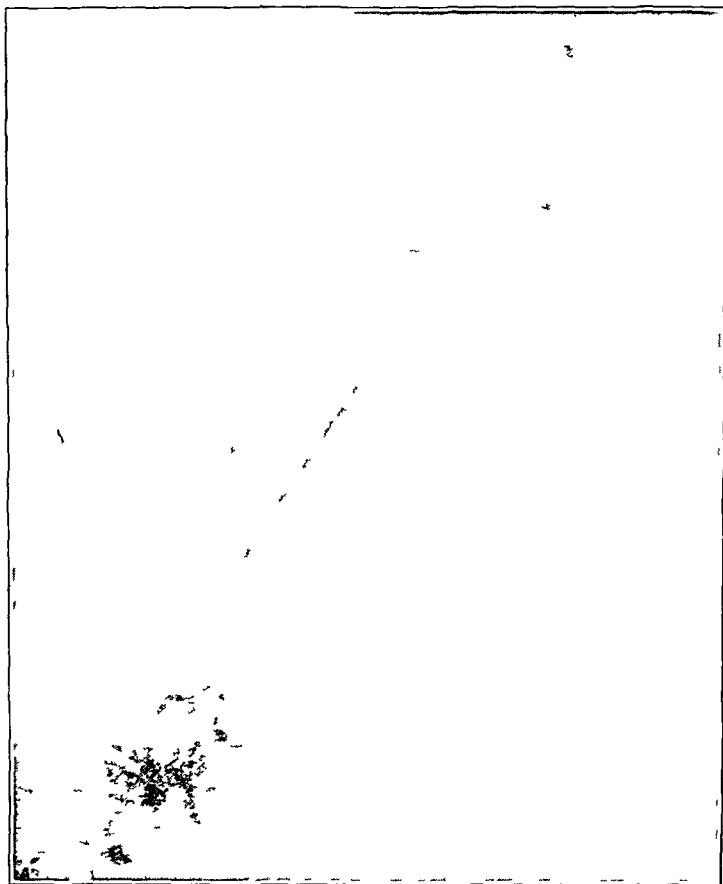


Fig 10 (Case 2)—Complete consolidation, four and one-half months after application of the Delbet splint

Oct 13, 1920, union was firm clinically, and the roentgenogram (Fig 9) taken Oct 13, 1920, shows the amount of callus formed after wearing the Delbet splint for two months

Dec 14, 1920, all apparatus was removed Union was firm, and the ankle was only slightly limited in dorsiflexion

Jan 5, 1921, a roentgenogram (Fig 10) revealed complete consolidation of the callus, four and one-half months after the application of the Delbet splint There is a permanent shortening of  $1\frac{1}{2}$  inches (3.8 cm), causing the patient to limp slightly The plate was removed, Jan 6, 1921 The wound healed by first intention

CASE 3—*History*—A man, aged 42, May 28, 1920, sustained a fracture of both bones of the leg in an automobile accident. The fracture was reduced, a plaster-of-Paris cast was applied and maintained for a period of fourteen weeks. The plaster was then removed, and, as no evidence of union was found, the patient was operated on and a bone graft inserted. The leg was then fixed in plaster-of-Paris for a period of seven weeks. About four months after the injury, all fixation was removed. Dec 29, 1920, the patient was sent to the University Hospital for treatment of nonunion.

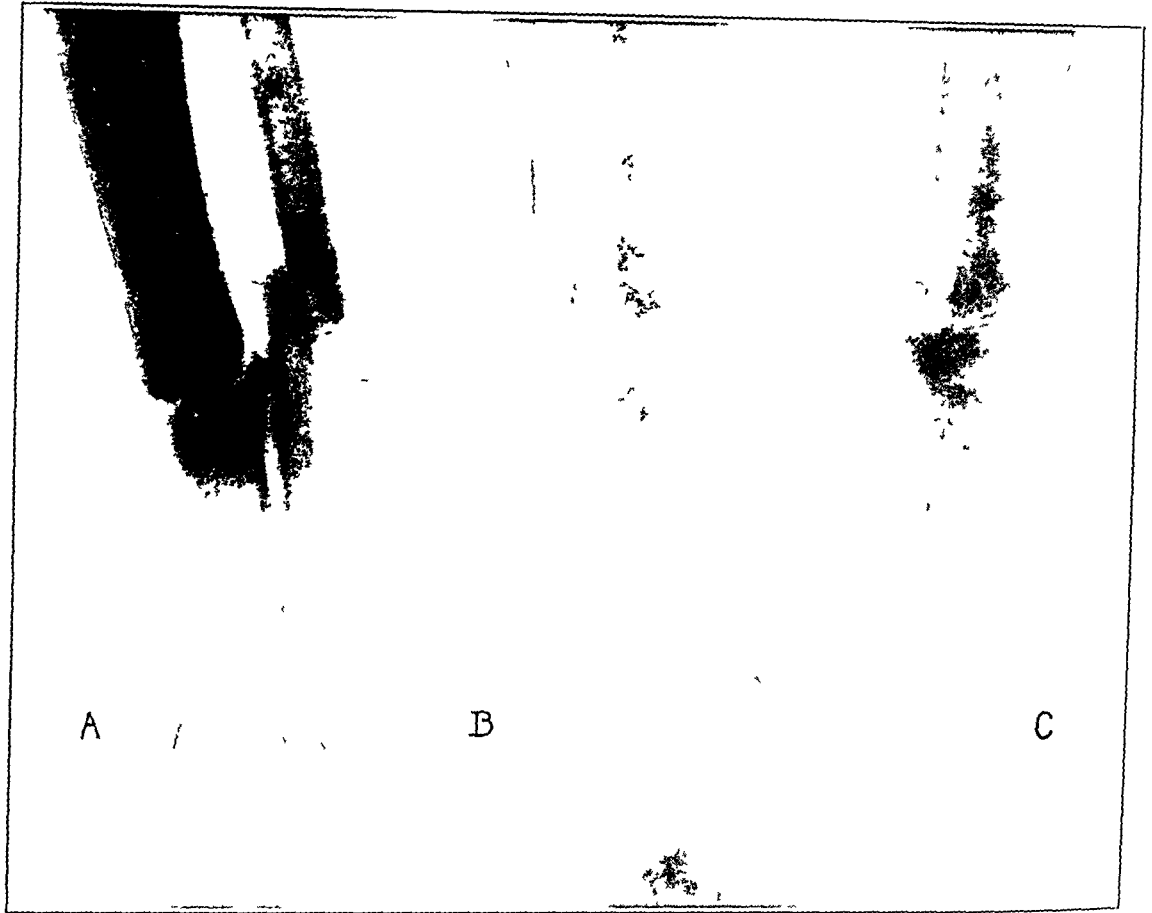


Fig 11 (Case 3)—*A*, ununited fracture of seven months' standing, showing evidence of fragments of bone graft, *B*, callus bridging fragments, four months after application of Delbet splint, *C*, end-result with union, seven months after application of Delbet splint.

*Examination*—There was a linear scar over the internal aspect of the tibia of the left leg—site of the previous operation—and an ununited fracture of the tibia at the junction of the middle and lower thirds of the leg, free motion between the fragments with pain, and 1 inch (2.5 cm) shortening. The roentgenogram (Fig 11), taken Dec 30, 1920, shows a fracture of both the tibia and fibula, with eburnation of the ends and some callus formation. Extending into the medullary canal of the proximal and distal fragments of the tibia is an old graft, with no union of either bone.

*Diagnosis*—Pseudarthrosis of the tibia and fibula.

*Operation*—Jan 7, 1921, the ends of the fragments were freed and the sclerotic bone and old graft were removed. A new graft was cut in the form of a truncated cone and wedged across between the upper and lower fragments (after the method of Gallie). Periosteal grafts were then taken from the opposite leg and strips were placed on three sides of the tibia. During the application of the plaster, an assistant twisted the foot and, it was feared at that time, displaced the graft.

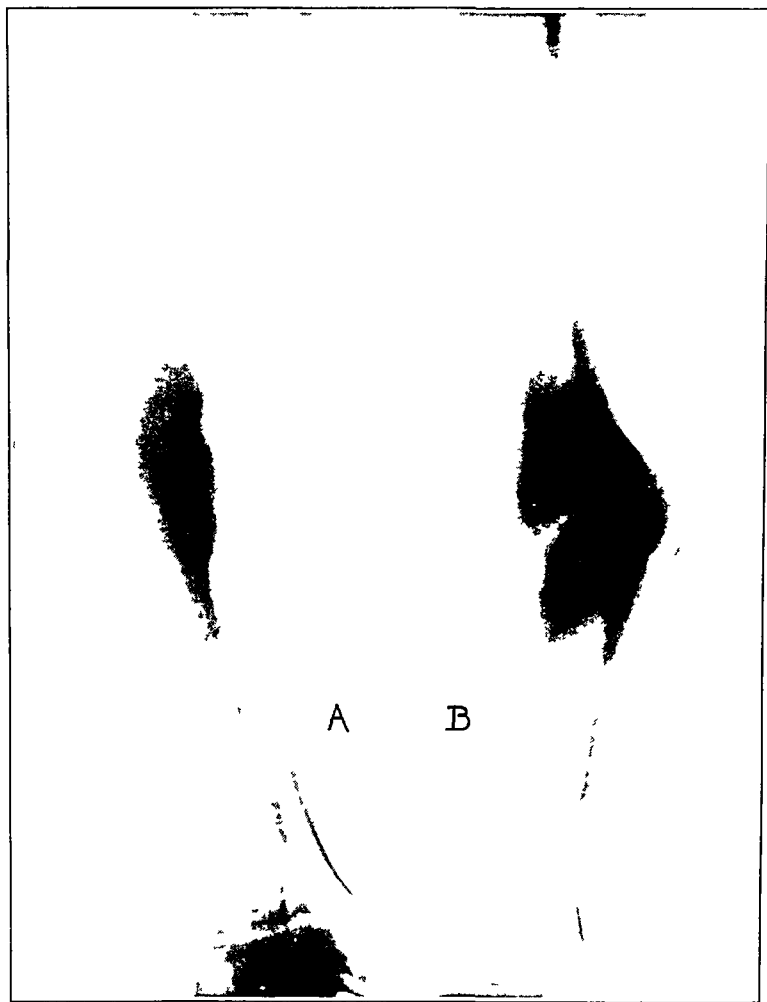


Fig 12 (Case 4)—A, fracture with nonunion and marked internal bowing, B, lateral view

*Course*—Jan 10, 1921, the plaster was split and the wound inspected. The graft was found to be displaced and to be sloughing its way through the skin. The removal of the graft was followed by sepsis. The plaster was therefore removed and a splint applied, holding the leg in good position and allowing for dressings.

Feb 25, 1921, the sepsis had cleared up and the wound was granulating. There was no evidence of union. A Delbet walking splint was applied and the patient was encouraged to walk.

April 12, 1921, the patient had been walking with the Delbet splint for about six weeks. There was still motion between the fragments but it was not nearly so marked as before application of the Delbet splint. The patient was seen again, June 13, 1921, and the roentgenogram of the same date (Fig 11 *B*) revealed definite production of callus between the fragments of both the tibia and fibula. Clinically, the union was quite firm.

Sept 20, 1921, the roentgenogram (Fig 11 *C*) demonstrated bony union. The patient walked without any support and did not complain of any pain. His only symptom was a feeling of weakness and slight limitation of motion in the ankle.

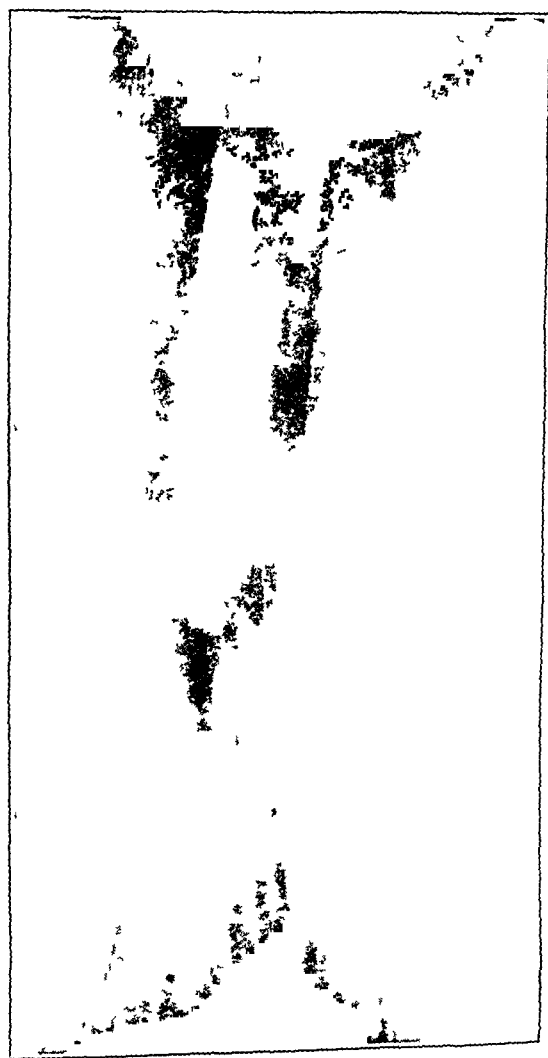


Fig 13 (Case 4)—Mortising operation

**CASE 4—History**—A man, aged 33, one year previously had been in an automobile wreck in which he sustained a compound fracture of the right tibia and fibula. The fracture was reduced and fixed in plaster for a period of seven weeks. Operation was then performed, the ends of the fragments being freshened but no internal fixation was used. A plaster-of-Paris cast was worn for three months subsequently. On removal there was motion between

the fragments. The patient had tried all sorts of treatment and supports of various kinds, but nonunion had been the result and in addition there was pronounced inward bowing at the site of fracture.

*Examination*—Dec 1, 1920, there was a scar, 4 inches (10 cm) long, over the mesial surface of the tibia, with pronounced inward bowing at the site of fracture. There was motion between the fragments without pain, one-half inch (12 cm) atrophy of the calf and 1 inch (25 cm) shortening of the leg. The roentgenogram (Fig 12), taken Dec 2, 1920, revealed a simple transverse fracture between the middle and lower thirds of the tibia, with marked

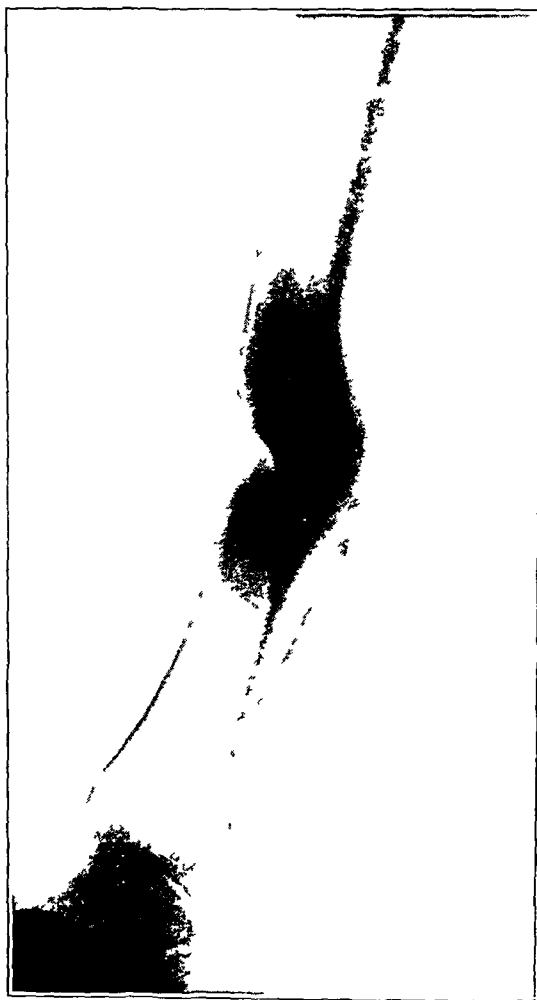


Fig 14 (Case 4)—Callus uniting all four fragments, four and one-half months after application of the Delbet splint

sclerosis of the ends of the fragments and inward angulation of about 30 degrees. There was a space still present between the ends of the tibia and fibula. The diagnosis was pseudarthrosis.

*Operation*—Dec 8, 1920, the ends of the fragments were freed, a mortise was made and held by beef bone pegs. Figure 13 is a reproduction of a roentgenogram taken shortly after operation.

*Course*—Dec 20, 1920, the sutures were removed. There was no evidence of infection.

Jan 2, 1921, at the upper portion of the wound, there was a small sinus discharging a thin serous material.

Jan 11, 1921, the patient had had a rise in temperature, with swelling at the site of operation and formation of an abscess.

Jan 12, 1921, an incision was made, drainage was established and the beef bone pegs were removed. From this time until the middle of March, dressings were required and the fragments were immobilized in a satisfactory position. March 17, the wound was granulating and there was free motion between the fragments. It was then decided to try to stimulate callus formation by the use of a Delbet splint. The splint was applied March 20.

April 24, 1921, the Delbet splint was removed. There was definite motion between the fragments but there was not the freedom of motion which there had been before the Delbet splint was applied.

July 14, 1921, the patient returned and the Delbet splint was removed. Examination revealed firm union. The patient had been walking on a Delbet splint for about four months. The callus formation is shown in Figure 14. The patient was discharged wearing a brace to prevent any recurrence of the deformity.

# BONE ATROPHY A CLINICAL STUDY OF THE CHANGES IN BONE WHICH RESULT FROM NONUSE\*

NATHANIEL ALLISON, M D, AND BARNEY BROOKS, M D

ST LOUIS

- I Introduction
  - (1) Summary of previous experimental study,
  - (2) Object of present study
- II Material studied
  - (1) Adults,
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- III Relation between changes in bone as a result of lack of use and the cause of the nonuse
- IV Character of changes in adults
- V Character of changes during period of growth
- VI Effect of nonuse on growth of bone
- VII Effect of nonuse on regeneration of bone
- VIII Recovery from bone atrophy
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## I INTRODUCTION

In a previous experimental study of the atrophic changes in bone which follow nonuse of an extremity, it was found that these changes were the same following nerve paralysis, joint injury and mechanic fixation of the extremity. The degree of atrophy of the bone was directly proportional to the degree of nonuse, regardless of the experimental method used to produce nonuse. Mechanical fixation produced as rapidly developing and as marked bone atrophy as nonuse due to section of nerves or injury to joints.

In this experimental study it was found that nonuse of an extremity of an adult resulted in the bones of this extremity becoming lighter, more fragile and more permeable to the roentgen ray. The length of the bones in adults was unchanged. The diameter of the shaft of the bone was slightly diminished. The diameter of the medullary canal was markedly increased. The cortex of the shaft was thus diminished in thickness. The trabeculae of the spongy bone became thinner, and in part disappeared. In prolonged nonuse, the cortical bone of the shaft became porous. If the period of nonuse of an extremity was concurrent with the period of growth of the individual, the processes of atrophy and growth operated together, and the bones of the nonused

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extremity showed not only the same initial changes as were found in the bones of the adults, but also changes which were the result of an inhibition of growth. The bones were relatively shortened, the diameter of the shafts was diminished, the diameter of the medullary canals was relatively increased, and the shape of the bones was altered. The power of regeneration, the chemical composition and the physical characteristics of bone as a tissue were not changed by nonuse.

In this experimental study, the conclusion was therefore reached that the process of bone atrophy was not a change in the characteristics of bone as a substance but that the process of bone atrophy is a change in the amount of bone present. The process of bone atrophy affects the size, shape, thickness, length, weight and texture of the whole bone, but the chemical composition, the physical characteristics and the regeneration of bone are not changed. Bone atrophy is a quantitative rather than a qualitative change.

The object of this study was to observe the changes in bone which result from lack of use of extremities in various clinical conditions, and to compare these observations with those made on experimental animals.

## II THE MATERIAL STUDIED

The material which was studied consisted of the following groups of cases: (1) poliomyelitis, (2) spastic paralysis, (3) peripheral nerve injuries, (4) Friedreich's ataxia, (5) pseudomuscular atrophy, (6) syringomyelia, (7) chronic infectious arthritis, (8) tuberculosis of bone, (9) acute pyogenic osteomyelitis, (10) ischemic contracture, (11) fracture, (12) congenital deformities, and (13) astasia abasia.

In those groups in which a large number of persons were available, cases were selected so as to include various ages and periods of existence of the disabling disease. In all cases, the age, the duration of the disability and the extent of the disability were obtained. When the lack of use was unilateral, the bones of both the used and nonused extremities were studied. The bones were studied by means of roentgen-ray examination. In some instances the bones were available for gross and microscopic study. The bones were studied as to length, thickness, diameter of the medullary canal, thickness of the cortex of the shaft and the number and thickness of the trabeculae of the cancellous bone. In children the epiphyseal cartilages were compared as to regularity and thickness. It was, of course, fully realized that measurements of bones from roentgenograms is at best not accurate, but great care was taken to have the bones as nearly as possible in the same position, and at the same distance from the tube and plate. Thus the measurements were accurate for comparison.

*Changes in Bone Resulting from Nonuse in Adults*—The following examples illustrate the changes in bone in adults which result from lack of use.

CASE 1—*Peripheral nerve injury* A colored man, aged 26, two years previously had caught his left arm in a belt on a revolving wheel, following which there was complete motor and sensory paralysis of the entire left forearm and a motor paralysis of the left arm. There was no bone injury. Sixteen months previously the brachial plexus had been sutured. Since operation there had been only a slight recovery from the motor paralysis of the arm, and no recovery of motion in the forearm. Sensation was completely recovered slowly in the entire extremity. Examination revealed marked muscle atrophy of the entire extremity with no contractures.

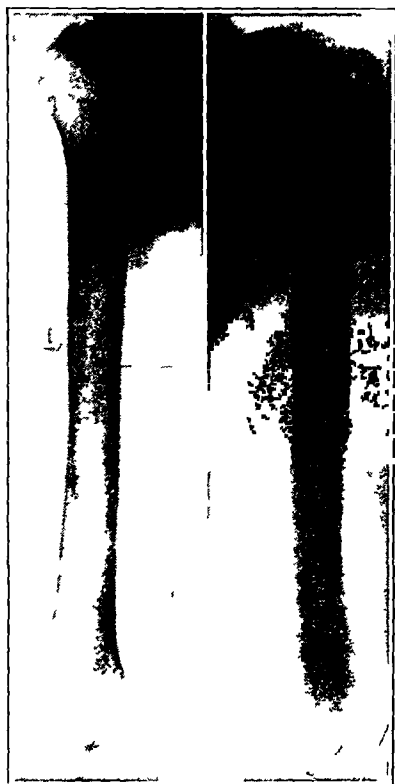


Fig 1—Roentgenogram of the right and left humerus in Case 1, a man, aged 26, with a brachial plexus injury of two years' duration. The marked diminution in thickness of the cortex of the shaft and of the left humerus, and the decreased density of the cancellous bone may be noted. The diameter of the medullary canal is markedly increased and the entire thickness of the shaft is slightly decreased. Compare the illustrations with the measurements recorded in the description of Case 1.

Roentgenograms of both humeri were studied. The right humerus appeared normal. The left humerus showed marked thinning of the cancellous bone of its extremities. There was a marked increase in the diameter of the medullary canal with a corresponding thinning of the cortical bone of the shaft. On close inspection linear striae of decreased density were noted in the cortical bone of the shaft (Fig 1).

CASE 2—*Spastic paralysis* A man, aged 60, had an apoplectic stroke, thirteen months previously, which resulted in a complete right hemiplegia. Three months after onset, he was able to walk. There had been a gradual improvement in both the arm and leg. He was able to walk with only a slight limp at the time of examination. The right hand, however, had not recovered to the point of usefulness. There was a moderate flexion contracture of the hand and wrist. There was no demonstrable muscle atrophy. The circumferences of the forearms and calves were equal on the two sides. There was voluntary power in all muscles of the right arm and forearm.

Two years previously the patient had fractured the left radius near the wrist joint. From this injury there was a prompt and complete recovery.

Roentgenograms of both forearms and hands were studied. There was a very striking difference in the roentgenograms of the two hands. All of the bones of the right hand showed marked thinning of the cortex of the shafts due to increased diameters of the medullary cavities. The trabeculae of the cancellous bone were fewer in number and thinner. The shafts of the bones

TABLE 1—MEASUREMENTS OF BONES IN CASE 1

	Right, Cm	Left, Cm
Length	32.0	32.0
Diameter at middle of shaft	2.3	2.1
Diameter of medullary canal (middle of shaft)	1.1	1.6
Thickness of cortex (middle of shaft)	0.6	0.25

TABLE 2—MEASUREMENTS OF BONES IN CASE 3

	Right Radius, Cm	Left Radius, Cm	Right Tibia, Cm	Left Tibia, Cm
Length	24.1	24.6	37.5	37.8
Diameter of shaft	1.7	1.5	3.1	2.6
Diameter of medullary canal	0.7	0.6		
Thickness of cortex	0.5	0.45		

showed evidences of increased porosity as well as decrease in thickness. A difference in the bones of the forearm was distinct but less marked than it was in the bones of the hand. The left radius showed a healed Colles' fracture.

The contracture of the right hand did not permit the taking of roentgenograms from which comparative measurements would have been of any value (Fig. 2).

CASE 3—*Syringomyelia* A white man, aged 38, at the age of 14 years, noticed a weakness in the left arm. At 17 years of age, a weakness of the left leg was noticed. There was a similar weakness in the right arm and right leg at the ages of 29 and 32. The weakness progressed until eight years previously, when he could get about only with assistance. For the last two years the patient had been able to get only from a bed to a chair. On examination he presented the characteristic picture of advanced syringomyelia, with marked muscle weakness and muscle atrophy of the extremities. There was a complete dissociation of sensation, but no complete muscle paralysis. The skin of both hands and feet showed typical "trophic" ulcers.

Roentgenograms of all the bones of the extremities were studied.

The bones of both arms and legs showed abnormal thinness of the cortex of the shafts and of the cancellous bone of the extremities. The cortical bone of the shafts of all bones was slightly more porous than normally. In gen

eral the bone atrophy was not advanced. There was, however, a definite correspondence in the amount of bone atrophy and the extent of loss of function in the extremities. There was no evidence of any influence on the normal growth of the bones in length or shape (Fig. 3).

**CASE 4—Ischemic contracture** A white boy, aged 16 years, one year previously fell and fractured the left radius. Splints were applied and a typical ischemic contracture developed. On examination there was a flexion contracture of the left hand and wrist with marked muscle atrophy and complete



Fig. 2—Roentgenogram of the bones of the forearms and hands in Case 2, a man, aged 60, suffering from a right hemiplegia of thirteen months' duration. The atrophic changes in the bones of the right extremity are not so well shown in the reproductions as in the original plates. A marked difference, however, can be seen in the appearance of the right and left first metatarsal bones.

disability. There was very slight motion in the fingers. The contracture was overcome by excision of the carpus. Roentgenograms were made of both forearms and hands after the contracture had been relieved.

The bones of the left hand and forearm showed marked bone changes. There was a healed fracture of the radius in the distal third. The cancellous bone of the distal ends of the radius and ulna was markedly thin. There was

thinning of the cortex of the shafts of all the bones in the hand and forearm. The diameter of the shafts of all bones was slightly decreased. There was a decrease in length of both bones of the forearm. The epiphyseal lines were completely absent in all bones of the left forearm. The distal epiphyseal line of the right radius was present.

**CASE 5—*Infectious arthritis*** A white woman, aged 52, six years previously received a crushing injury to her right foot, which was followed by an infection of the tarsal bones. The infection resulted in destruction of the cuneiform bones and parts of the astragalus and os calcis. The infection healed with an extreme valgus deformity of the foot. There was no infection of the tibia or fibula. The patient had not used the right leg since the injury. She got about on the left leg with the assistance of crutches. There was marked muscle atrophy in the right calf. Roentgenograms of both tibias were studied.

There was a very marked difference in the appearance of the two tibias. The left tibia appeared normal. The right tibia showed extreme thinning of

TABLE 3—MEASUREMENTS OF BONES IN CASE 4

	Right Radius, Cm	Left Radius, Cm
Length	23.4	22.4
Diameter of shaft	1.3	1.1
Diameter of medullary canal	0.6	0.5

TABLE 4—MEASUREMENTS OF BONES IN CASE 5

	Right Tibia, Cm	Left Tibia, Cm
Length	38.8	38.0
Diameter of shaft	2.6	2.6
Diameter of medullary canal	2.4	1.9
Thickness of cortex of shaft	0.1	0.35

the cancellous bone of its extremities. The medullary canal was markedly increased in diameter. The cortical bone of the shaft was thin and porous. The diameter of the shaft was not decreased. The right tibia measured slightly longer than the left (Fig. 5).

**CASE 6—*Fracture*** A white man, aged 56, two years previously was struck by a heavy piece of lumber which broke both bones of the left leg. The fracture was compound, but no suppuration followed, and the small open wound closed in a few days. The fracture was treated with plaster but failed to unite. The patient had borne no weight on the left leg since the accident. He got about using the right leg and crutches. Examination revealed a nonunited fracture of the left tibia and fibula at the junction of the middle and distal thirds. There was free, painless, false motion at the level of the fracture. Roentgenograms of both tibias were studied, and the character of the bone of the left tibia and fibula was observed at operation, which was performed for the cure of the nonunited fracture.

The bones of the left leg and foot showed extreme bone atrophy. The cancellous bone of the extremities of the long bones and of the entire tarsal bones was very thin. The trabeculae were decreased in number and density. The medullary canal of the long bones was increased in size. The cortex of the shafts of the long bones was thin and porous.

*Changes in Bone Resulting from Lack of Use During Growth*—The following cases were chosen as examples showing the changes in bone which result from lack of use during the growing period

CASE 7—*Peripheral nerve injury* A white girl, aged 9 years, had a single congenital dislocation of the left hip. The deformity was such that the patient got about with a slight limp. There was no apparent muscle atrophy. An open operation was performed, and the dislocation was reduced. Immediately following operation, there was a complete sciatic nerve paralysis. The patient

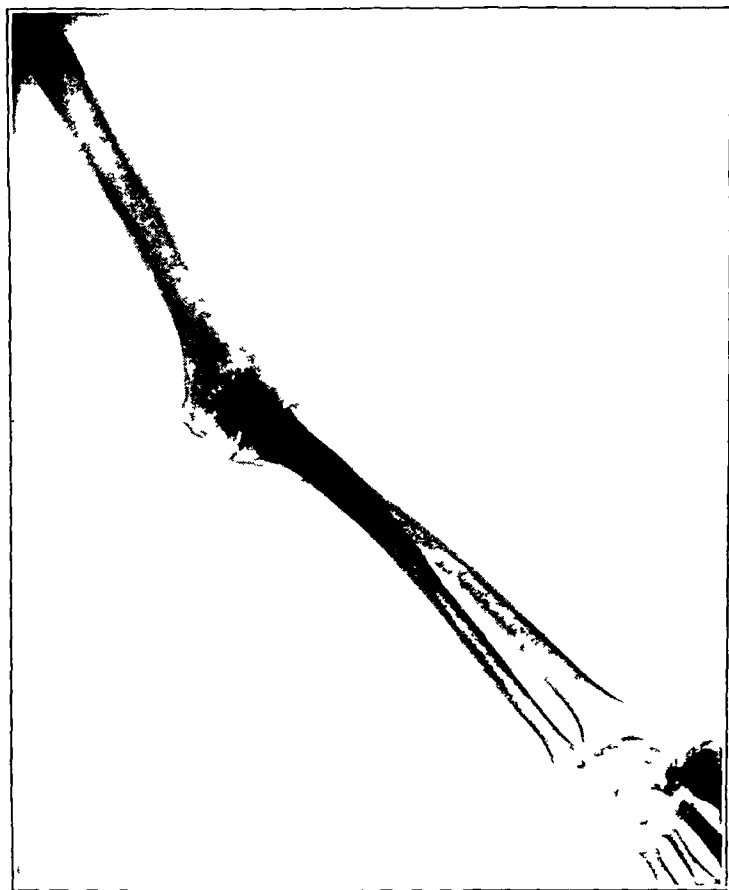


Fig 3—Roentgenogram of the bones of the left upper extremity in Case 3, a man, aged 38, suffering from syringomyelia. The first symptoms of the disease appeared twenty-four years previously. The progress had been slow and the sensory paralysis was much more advanced than the motor paralysis. The bones show a moderate degree of atrophy.

was under observation for a period of five years after the nerve injury. At the end of this period there was some recovery of sensation. There was a slight return of power in the hamstring muscles. Otherwise, there was a complete motor paralysis of all muscles supplied by the sciatic nerve, with marked muscle atrophy. The patient was unable to use the leg in walking. Roentgenograms of both lower extremities were made five years after the nerve injury. Those of both tibias were studied in detail.

The bones of the right leg appeared normal for a 14 year old child. Both epiphyseal cartilages were present in both bones. The contours of both tibiae and fibulas were normal. Both bones of the left leg were abnormal. The fibula had a very small shaft. The epiphyses were large in comparison with the shaft, but were smaller than normal. Both epiphyseal cartilages of the fibula were absent. The left tibia showed a decrease in the diameter of the shaft, and a relative increase in the diameter of the medullary canal. The epiphyses of the tibia were large in comparison with the shaft, but smaller than those of the normal tibia. The cortex of the shaft was thinner than that of the right tibia. The proximal epiphyseal cartilage was apparently absent. The distal cartilage showed faintly. The lengths of both tibiae and fibulas were diminished (Fig 7).

TABLE 5—MEASUREMENTS OF BONES IN CASE 7

	Right Tibia, Cm	Left Tibia, Cm
Length	33.5	32.5
Diameter of shaft	2.1	1.8
Diameter of medullary canal	1.3	1.2
Thickness of cortex of shaft	0.4	0.3
Diameter of proximal epiphyses	7.0	6.5

TABLE 6—MEASUREMENTS OF BONES IN CASE 8

	Right Tibia, Cm	Left Tibia, Cm	Right Femur, Cm	Left Femur, Cm
Length	28.9	30.2	35.2	36.0
Diameter of shaft	1.5	1.7	1.7	1.9
Diameter of medullary canal	0.9	1.0	0.9	0.9
Thickness of cortex	0.3	0.35	0.4	0.5
Diameter of epiphysis	5.7	6.3	6.6	7.0

TABLE 7—MEASUREMENTS OF BONES IN CASE 9

	Right Radius, Cm	Left Radius, Cm
Length	19.5	25.0
Diameter of shaft	1.3	1.6
Diameter of medullary canal	0.8	0.25
Diameter of epiphysis (distal)	2.7	3.6

CASE 8—*Spastic paralysis*. A colored girl, aged 11 years, had had a right hemiplegia since birth. She was restless and feeble-minded and had never walked. The right leg and arm showed the typical picture of complete spastic paralysis. The left arm and leg were not paralyzed.

Roentgenograms of the bones of both lower extremities were studied. All the bones of both extremities showed distinct evidence of lack of function. The changes in the bones of the right lower extremity were much more marked than in the left (Fig 8).

CASE 9—*Ischemic contracture*. A white boy, aged 17 years, at the age of 10 years fell from a tree and fractured the bones of the right forearm. Splints were immediately applied to the arm. There was a great deal of pain. The splints were not removed for two weeks. When the dressings were removed, there was extensive ulceration of the skin of both anterior and posterior surfaces of the wrist and palm. The fingers could not be straightened. Grad-

usually a marked flexion contracture developed. The hand had not been used since injury—the thumb was adducted across the palm. There were deep scars on the flexor and extensor surfaces of the wrist, as well as a deep scar on the thenar eminence. The muscles of the forearm were markedly atrophied. There was no evidence of sensory or motor paralysis. The entire forearm and hand were shorter and smaller than normal. The patient did not use the hand.

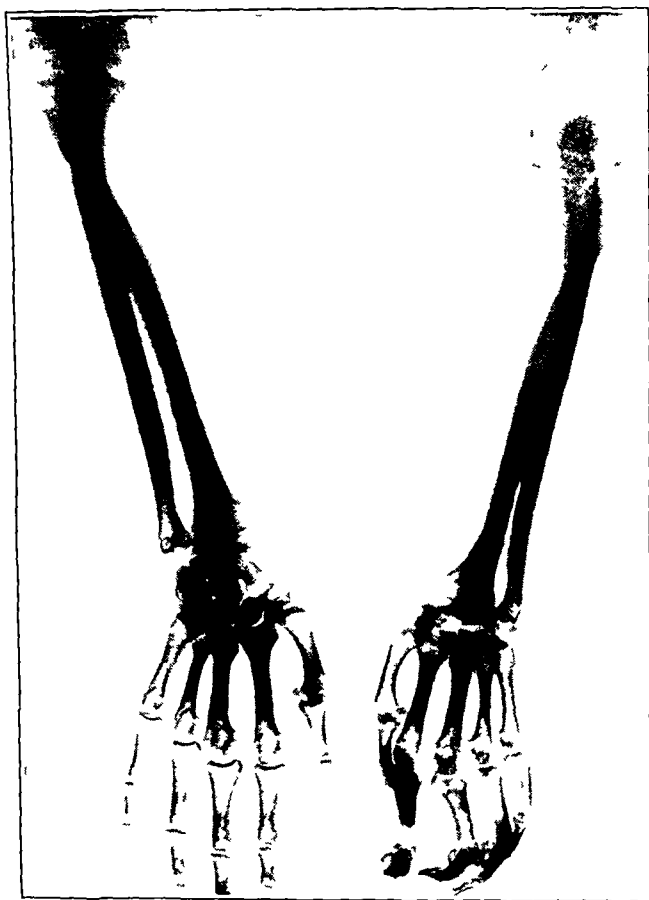


Fig 4—Roentgenogram of the bones of both forearms in Case 4, a boy, aged 16 years, suffering from an ischemic contracture of the left forearm, of one year's duration. There is a diminution in size and density of all of the bones of the left forearm and hand. The atrophic changes in the bones of the forearm are more marked in the distal portions of the bones. The distal epiphyseal cartilages of the left ulna and radius are absent.

Roentgenograms of both forearms and hands were studied. There was a marked diminution in the size and length of all bones of the right forearm and hand. The distal end of the radius and ulna showed more marked changes than the proximal ends. The cancellous bone of the distal end of the radius and of the bones of the hand was more porous. The diameter of the shafts of the bones was relatively decreased. The medullary canals were relatively increased. The cortex of the shaft was the same as that of the normal



extremity The epiphyseal lines were present in the bones of the left forearm The epiphyseal lines of the bones of the right forearm had disappeared (Fig 9)

CASE 10—*Tuberculosis of hip* A white girl, aged 6 years, two years before had begun to limp One year previously, examination revealed the typical clinical picture of tuberculosis of the hip There was at this time only slight bone destruction in the right acetabulum The right knee was slightly swollen and tender Roentgen-ray examination disclosed no bone destruction at the knee Tuberculosis of the knee was suspected, but could not be proved The patient was treated by traction in bed for six weeks, after which a spica cast was applied to the entire right lower extremity The patient has been continuously in a cast for a year The cast had been changed four times during this period, but had never been off for more than a day The patient had been able to get about with crutches and a high sole on the left shoe, for the last three months For the last six months there had been no fever and the general condition of the patient had been very good

TABLE 8—MEASUREMENTS OF BONES IN CASE 10

	Right Tibia, Cm	Left Tibia, Cm
Length	27.2	27.0
Diameter of shaft	1.3	1.6
Diameter of medullary canal	1.0	1.0
Thickness of cortex	0.30	0.15
Diameter of epiphysis	5.4	5.0

TABLE 9—MEASUREMENTS OF BONES IN CASE 11

	Right Tibia, Cm	Left Tibia, Cm	Right Femur, Cm	Left Femur, Cm
Length	34.0	33.6		
Diameter of shaft	2.1	1.9	2.6	2.4
Medullary canal	1.4	1.3	1.6	1.5
Diameter of epiphysis	7.0	6.8		

Examination immediately after removal of the cast revealed very little motion in the right hip and knee There was marked muscle atrophy of all the muscles of the right thigh and leg

Roentgenograms of all the bones of both lower extremities were studied The right hip joint showed extensive destruction of the acetabulum and head of the femur There was no evidence of a tuberculous focus in the region of the knee joint All bones of the right lower extremity showed extreme atrophic changes The tibia was chosen for comparative study since this bone was not involved in the disease process

The right tibia showed a marked decrease in density of the cancellous bone The diameter of the shaft was decreased, the cortex was thinner, the right tibia was slightly longer than the left, the epiphyseal lines were all present The epiphyseal lines in the right tibia were abnormally regular (Fig 10)

CASE 11—*Osteomyelitis of femur* A white girl, aged 12 years, at the age of 6 years had suffered from acute osteomyelitis which involved the distal end of the left femur The site of the infection was opened and drained There was a discharge from the bone for a period of one year The wound then closed, with the gradual reestablishment of normal function in the extremity For a period of eight months, the left lower extremity was not used At

the present time there is slight atrophy of the muscles in the thigh and calf on the affected side. Roentgenograms of the bones of both lower extremities were studied.

All the bones of the left lower extremity were slightly smaller in all measurements. The trabeculae of the cancellous bone were fewer in number but thicker, presenting the appearance of a coarser network. The epiphyseal lines were all present and did not vary on the two sides (Fig. 11).

The patient had a short period of nonuse during the growing period, which was followed by complete return of use of the extremity.

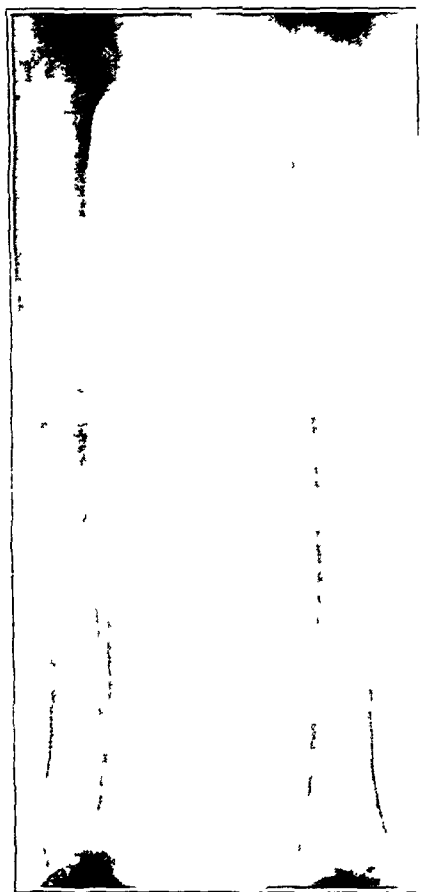


Figure 5

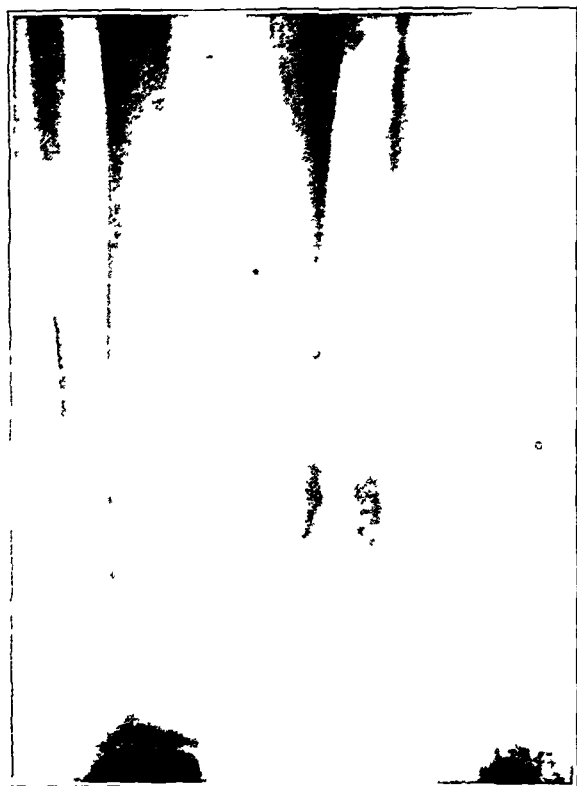


Figure 6

Fig. 5—Roentgenogram of the bones of both legs in Case 5, a woman, aged 52, who had not used her right leg for a period of six years because of a deformity of the foot which followed an acute infectious process in the tarsus. The bones of the right leg show advanced nonuse atrophy. The thick, compact cortex of the shaft of the right tibia is changed to thin porous bone. The illustration is characteristic of advanced bone atrophy which results from lack of use during the adult period.

Fig. 6—Roentgenogram of bones of the legs in Case 6, a man, aged 56, with a nonunited fracture of the left leg of two years' duration. The bones of the left leg, foot and ankle show marked atrophy.

CASE 12—*Fracture* A white boy, aged 14 years, at the age of 8 years fell and fractured the shaft of the right femur. The fracture healed in good position, and function was restored. Since this accident, however, the right femur had been refractured seven times, each time the result of a fall. The patient was first seen by us in October, 1920, at which time there was a lack of union in the eighth fracture of the shaft of the right femur, which had been sustained two months previously. The fracture had been treated by application of a plaster cast. The patient stated that each preceding fracture had been treated in a similar manner. Examination in October, 1920, revealed false motion in the middle third of the right femur. Roentgenograms disclosed lack of approximation of the fragments. Roentgenograms were made of all the bones of the body. There was nothing abnormal except in the bones of the right lower extremity. All bones of this extremity showed atrophic changes. There was marked decrease in the density of the cancellous and cortical bones. The bones were diminished in thickness and length as compared with the corresponding bones of the left extremity. All epiphyseal cartilages were

TABLE 10—MEASUREMENTS OF BONES IN CASE 12

	October, 1920		February, 1922	
	Left Tibia,	Right Tibia,	Left Tibia,	Right Tibia,
	Cm	Cm	Cm	Cm
Length	32.3	29.8	33.3	29.9
Diameter	2.0	1.7	2.2	1.9
Diameter of medullary canal	1.0	1.0	1.0	0.9
Thickness of cortex	0.45	0.35	0.6	0.5
Diameter of epiphyses			7.7	6.9

TABLE 11—MEASUREMENTS OF BONES IN CASE 13

	Right Tibia,	Left Tibia,	Right Fibula,	Left Fibula,
	Cm	Cm	Cm	Cm
Length	40.0	39.0	34.0	34.0
Diameter of shaft	2.5	2.0	1.5	0.5
Diameter of medullary canal	1.3	1.4		
Diameter of epiphyses	8.5	7.6		
Thickness of cortex	0.6	0.3		

present (Fig. 12). The fracture was treated by open operation and bone transplantation. The fracture united in twelve weeks. The patient then got about on crutches for a period of about six weeks, after which time he walked with no support. For the last year the patient had been using the extremity, with an extension sole for complete weight bearing. In February, 1922, the entire right lower extremity was smaller and shorter than the left. The measured shortening amounted to 3.5 inches (8.9 cm). Roentgenograms of the bones of both lower extremities were obtained.

In this patient, therefore, there was a period between the ages of 8 and 14 years in which there was a marked lack of use of one lower extremity as a result of repeated fractures. Finally there was a year of continuous usefulness of the extremity. Roentgenograms were obtained at the beginning and end of this period of usefulness of the extremity. This permitted the study of the changes which result from lack of use and also the effect on the bones of reestablishment of function. Furthermore, the period of observation was during the latter years of growth of the patient.

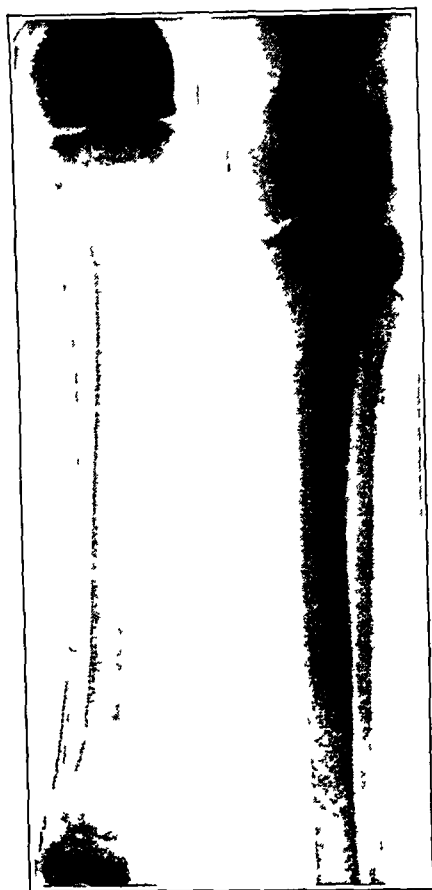


Figure 7

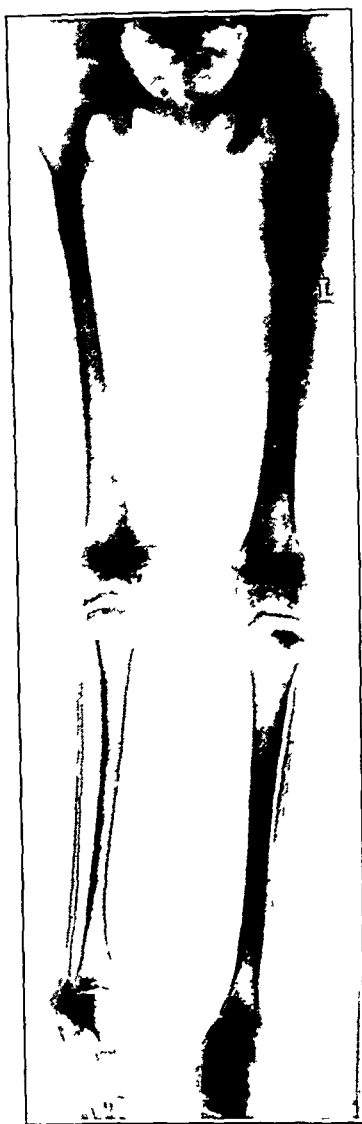


Figure 8

Fig 7—Roentgenogram of the bones of the legs in Case 7, a girl, aged 14 years, who had a complete muscle paralysis of the left leg due to injury of the sciatic nerve five years previously. Compare the shape and the appearance of the epiphyseal cartilages of the tibiae. The measurements of the bones are recorded in the description of Case 7.

Fig 8—Roentgenogram of the bones of the lower extremities in Case 8, a girl, aged 11 years, who had suffered from a right hemiplegia since birth. Compare the bones of the two extremities with the measurements recorded in the description of Case 8.

Roentgenograms of the bones of both lower extremities taken in 1922 demonstrated the bones of the affected extremity to be smaller and shorter than those of the normal extremity. The left tibia had increased in all dimensions. The right tibia had increased in thickness but not in length. All epiphyseal cartilages in the bones of the right extremity were absent. The proximal epiphyseal cartilages of the left tibia and fibula were faintly visible. There was a marked difference in the appearance of the cancellous bone of the right tibia from that seen in the left tibia and also from that seen in the right in the roentgenograms studied a year previously. The trabeculae of the can-

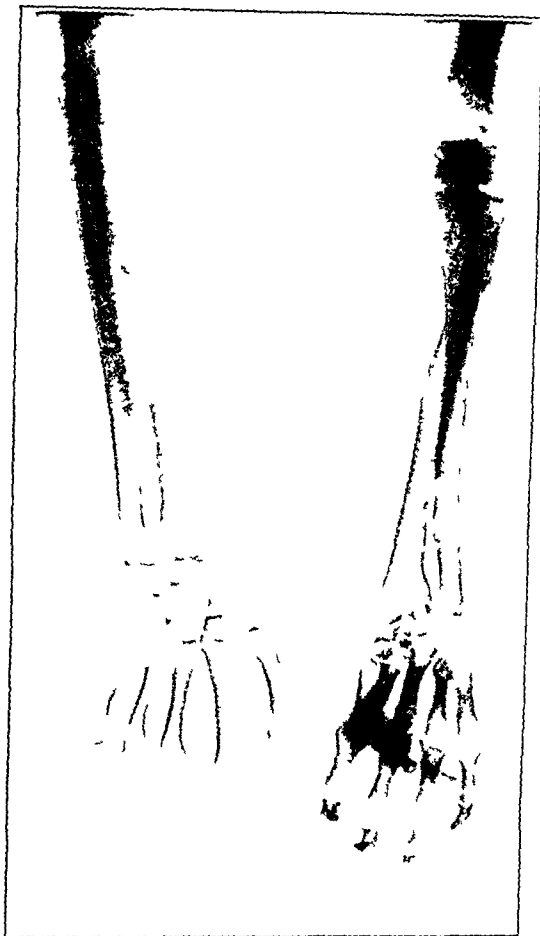


Figure 9

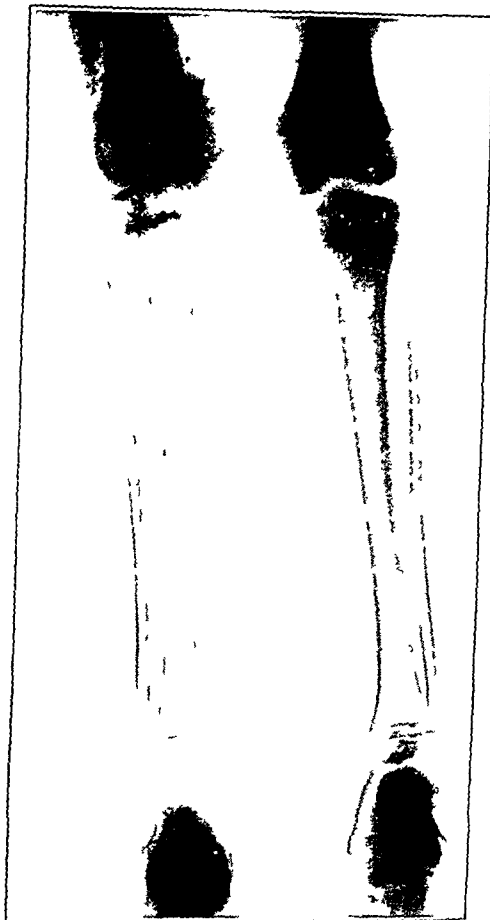


Figure 10

Fig 9—Roentgenogram of the bones of the forearms in Case 9, a boy, aged 17 years, with an ischemic contracture of the right forearm and hand. The disproportion of size of the bones of the right forearm and hand may be noted. The disproportion in length is greater than has been observed in other cases of nonuse. The epiphyseal cartilage may have been injured at the time of onset of the disease.

Fig 10—Roentgenogram of the bones of the legs in Case 10, a child, aged 6 years, with tuberculosis of the right hip of two years' duration. The entire extremity had been fixed in plaster for one year. The marked difference in the bones of the extremities may be noted. Compare the atrophic bones of the right leg with the illustrations of bone atrophy resulting from poliomyelitis.

cellous bone in the right tibia were fewer in number than in the corresponding areas of the left tibia, the individual trabeculae of the right tibia were thicker than in the left tibia and also thicker than in the right tibia of one year ago (Fig 13)

CASE 13—*Congenital deformity* A white boy, aged 15, was born with a unilateral left talipes equinovarus of marked degree. The patient began to walk at the usual age. There had been one operative effort made to correct the deformity. At the time of examination the patient walked without artificial support. The weight was borne on the distal ends of the lateral metatarsals. There was a marked limp and disability in gait. The muscles of the left thigh and calf were much smaller than those of the right.

Roentgenograms of the bones of both legs were studied. The bones of the right leg appeared normal. The bones of the left leg were thinner and shorter than normally. The cancellous bone was more porous than normally and the cortex of the shaft was diminished in thickness. The left fibula was strikingly thin. It was interesting to note, however, that the length of the left fibula and the right fibula was the same. All epiphyseal cartilages were present. Those in the bones of the left leg were more nearly closed than those in the bones of the right leg (Fig 14).

TABLE 12—MEASUREMENTS OF BONES IN CASE 14

	Lateral		Anteroposterior Roentgenograms			
	Roentgenograms		Jan 19, 1921		Dec 12, 1921	
	Right	Left	Right	Left	Right	Left
	Tibia	Tibia	Tibia	Tibia	Tibia	Tibia
	Cm	Cm	Cm	Cm	Cm	Cm
Length	23.4	23.3	23.5	23.4	24.7	24.7
Diameter of shaft	1.8	1.7	1.7	1.7	1.5	1.4
Diameter of medullary canal	0.7	0.7	1.0	1.0	1.3	1.1
Diameter of proximal epiphysis	2.7	2.6	4.1	4.1	4.3	4.3
Thickness of cortex	0.55	0.5	0.35	0.35	0.1	0.15

CASE 14—*Poliomyelitis* A girl, aged 5 years, was first seen in September, 1920, suffering from an acute attack of anterior poliomyelitis. The paralysis was complete in all extremities. The patient was under observation at the time of examination. There had been some recovery of motion in both upper extremities, but the lower extremities remained in a state of completely flaccid paralysis. The patient had been confined continuously to bed and to a chair. Roentgenograms of the bones of both legs were made Oct 20, 1920, Jan 19, 1921, and Dec 12, 1921.

Roentgenograms made Oct 28, 1920, one month after onset of the disease, revealed normal appearing bones. In the roentgenograms made Jan 19, 1921, three months later, there was a marked change in the appearance of the bones of both legs. The cancellous bone was much more porous. The cortical bone of the shaft was much thinner and showed linear striae of decreased density. There was a slight increase in length of the bones of both legs. Measurements of the diameters of the shafts and medullary cavities cannot be accurately compared because the roentgenograms taken in October, 1920, were lateral views and those made in January, 1921, were anteroposterior views.

The roentgenograms made Dec 12, 1921 fourteen months after the onset of the disease, were taken under the same conditions as those made Jan 19, 1921. A comparison of these two roentgenograms, therefore demonstrates accurately

the progress of the bone changes during a period of eleven months of complete lack of use in a growing child. The bones of both legs had become exceedingly thin. The trabeculae of the cancellous bone were much fewer and smaller. The thickness of the cortex had decreased markedly. The length of the bones had increased. The diameter of the shafts had decreased. The diameter of the medullary canals had increased. The width of the epiphyses had increased. Thus, the contours of the bones had changed (Figs 15, 16 and 17).

CASE 15—A white woman, aged 25, at the age of 4 years had an attack of acute anterior poliomyelitis which resulted in a complete paralysis of all the muscles of the left leg and a partial paralysis of the left thigh. Since the onset of the paralysis, the left lower extremity had not been used for walking. The patient had always walked with crutches and there had been no attempt at any time to make use of the paralyzed extremity either with or without artificial support. Examination revealed complete paralysis of the leg with marked muscle atrophy. The adductor group and the psoas muscles of the thigh had some power, otherwise the thigh muscles were completely paralyzed and atrophied.

TABLE 13—MEASUREMENT OF BONES IN CASE 15

	Right Tibia, Cm	Left Tibia, Cm
Length	40.0	34.6
Diameter of shaft	2.7	1.9
Diameter of medullary canal	1.7	1.1
Diameter of epiphysis (proximal)	7.8	6.6
Thickness of cortex	0.5	0.4

TABLE 14—MEASUREMENTS OF BONES IN CASE 16

	Right Tibia, Cm	Left Tibia, Cm
Length	35.1	37.0
Diameter of shaft	2.4	2.6
Diameter of medullary canal	1.7	1.7
Diameter of epiphyses (proximal)	7.3	8.3
Thickness of cortex	0.35	0.45

Roentgenograms of the bones of both lower extremities were studied. All of the bones of the left lower extremity, including the bones of the left pelvic girdle, were diminished in size and density. There was an extreme coxa valga deformity of the left femur, associated with a lack of development of the great trochanter and a relative overdevelopment of the lesser trochanter. The acetabulum was small and shallow. All epiphyseal cartilages were absent. The tibias were chosen for detailed comparative study. The right tibia appeared normal. The left tibia was shorter. The diameter of the shaft was diminished. The epiphyses were smaller than those of the left tibia, but in comparison to the size of the shaft they were large. The cancellous bone was more porous, and the cortex of the shaft was thin (Fig 18).

CASE 16—A white woman, aged 28, when 1 year old had an attack of acute anterior poliomyelitis which resulted in a complete permanent paralysis of all the muscles of the right leg and a partial paralysis of the thigh. The extensor muscles of the thigh were paralyzed. There was power in the hamstring muscles. There was marked muscle atrophy of the leg and less marked atrophy of the thigh. In spite of the extent of the paralysis, the patient had continu-

ously used the leg for walking. Roentgenograms of the bones of both lower extremities were studied. Considering the marked difference in muscles of the two legs, there was surprisingly little difference in the appearance of the bones of the two legs. The right tibia was slightly shorter and thinner. The cancellous bone was only slightly more porous. The diameter of the shaft was slightly decreased (Fig 19).

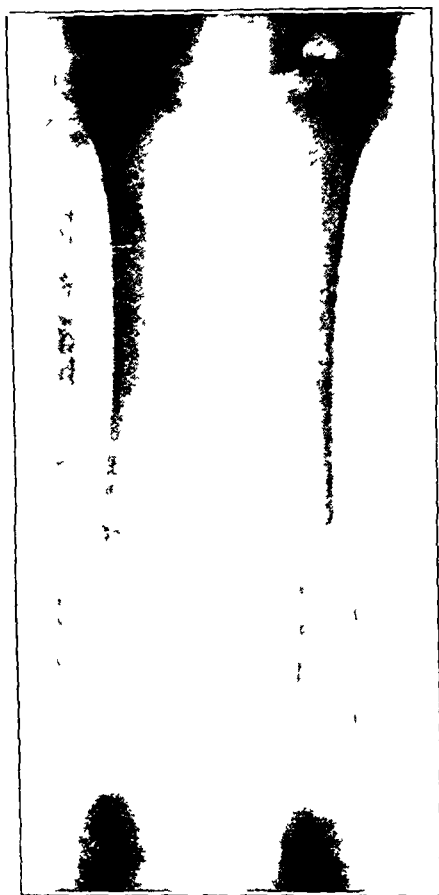


Figure 11

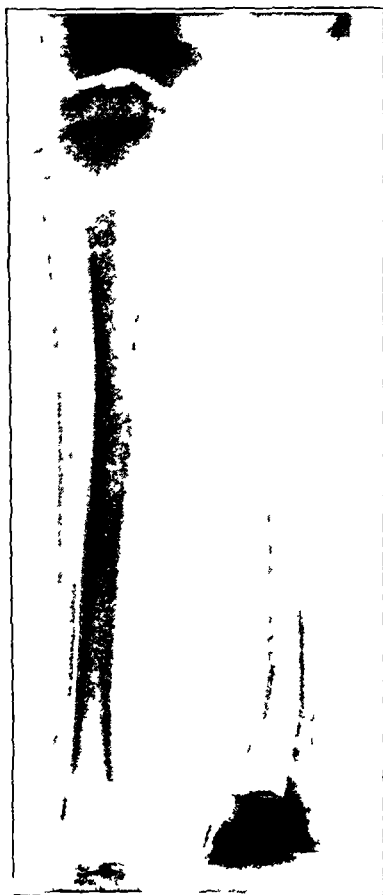


Figure 12

Fig 11—Roentgenogram of the bones of the legs in Case 11, a girl, aged 12 years, who did not use the right leg for a period of about eight months at the age of 6 years owing to acute osteomyelitis of the distal end of the femur. The recovery from the disability was complete. The unmistakable evidences of lack of use during the growing period are seen in the abnormal shape and size of the bones of the right leg.

Fig 12—Roentgenogram of the bones of the legs in Case 12, a boy, aged 14 years who had sustained repeated fractures of the right femur. These roentgenograms were made two months after the last fracture, at which time there was lack of union of the fragments due to malposition. The bones of the right leg show marked atrophic changes and growth disturbance. All epiphyseal cartilages are distinct, but they are thicker in the bones of the left leg. Compare with Figure 13.



### III RELATION BETWEEN CHANGES IN BONE AS A RESULT OF LACK OF USE AND THE CAUSE OF THE NONUSE

From the study of the changes in bones which followed lack of use from various causes in both children and adults, there was no evidence that the cause of the lack of use affected these changes in any manner. The same atrophic changes in bone were observed when the lack of use was due to anterior poliomyelitis, spastic paralysis, peripheral nerve injury, Friedreich's ataxia, pseudomuscular atrophy, syringo-

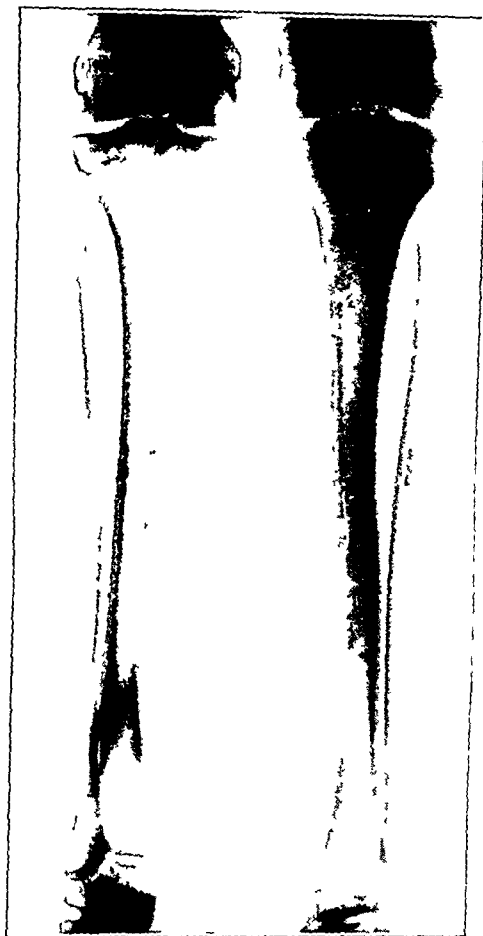


Figure 13

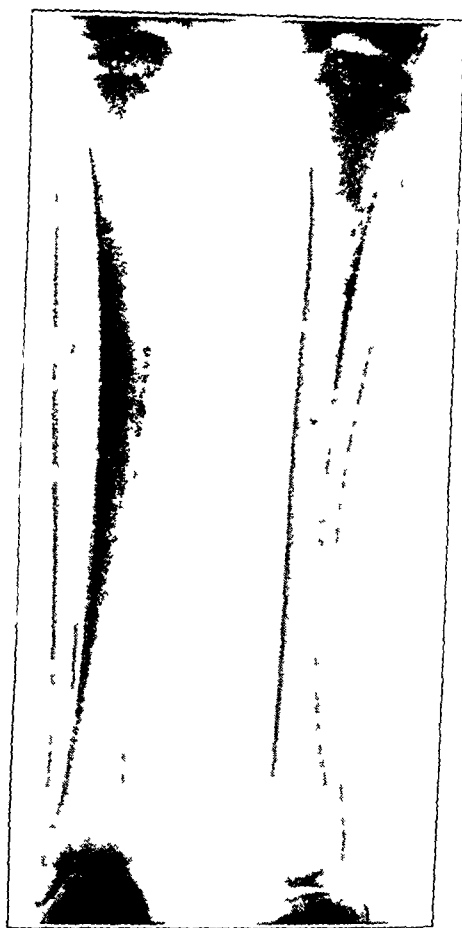


Figure 14

Fig 13—Roentgenogram of the bones of the legs in Case 12, after healing of the fracture of the femur and continuous use of the extremity for a period of about one year. The increase in thickness of the cortex of the shaft of the right tibia and the increased strength of the struts of the cancellous bone may be noted. The epiphyseal cartilages are absent in the bones of the right leg. Compare with the measurements recorded in the description of Case 12.

Fig 14—Roentgenogram of the bones of the legs in Case 13, a boy, aged 15 years, with a left congenital clubfoot. The bones of the left leg show the effects of incomplete function during the growing period. The fibula shows more change than the tibia on account of the position of the foot.

myelia, chronic arthritis, tuberculosis of bone, pyogenic osteomyelitis, contracture, fracture, congenital deformities and astasia abasia. The character of the changes was the same in all instances. The amount of the changes varied directly with the extent of the lack of use. There was absolutely no evidence that bone atrophy was ever the result of specific nerve influence on bone, and it is, therefore, unwarranted to assume that bone atrophy is ever a neurotrophic phenomenon. To emphasize this important point, Figures 7, 10, 12 and 17 show the changes in the tibias of children affected by anterior poliomyelitis, peripheral nerve injury, tuberculosis of the hip and fracture of the

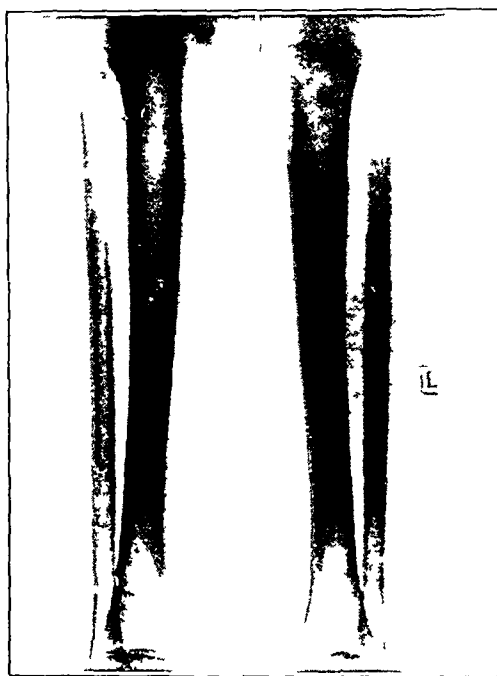


Fig 15—Roentgenogram of the bones of the legs in Case 14 one month after the onset of an attack of acute poliomyelitis. The bones of both legs appear normal.

femur, and Figures 1, 2, 3, 5 and 6 show the changes in the bones of adults which followed peripheral nerve injury, spastic paralysis, syringomyelia, fracture and infectious disease.

#### IV CHARACTER OF CHANGES IN ADULTS

The initial atrophic changes in bone due to nonuse of an extremity are the same regardless of the age of the individuals. The ultimate result of the changes in the bones of an extremity which is not used is different in the person who has reached his complete growth from

that in the person who is in his growing period at the time of onset of nonuse. In the former instance, the process of bone atrophy is operating alone. In the latter, the process of bone atrophy is associated with the process of growth which is inhibited but not arrested by nonuse.

The changes in bone which result from lack of use during adult life are such that the general shape and contour of the bone as a

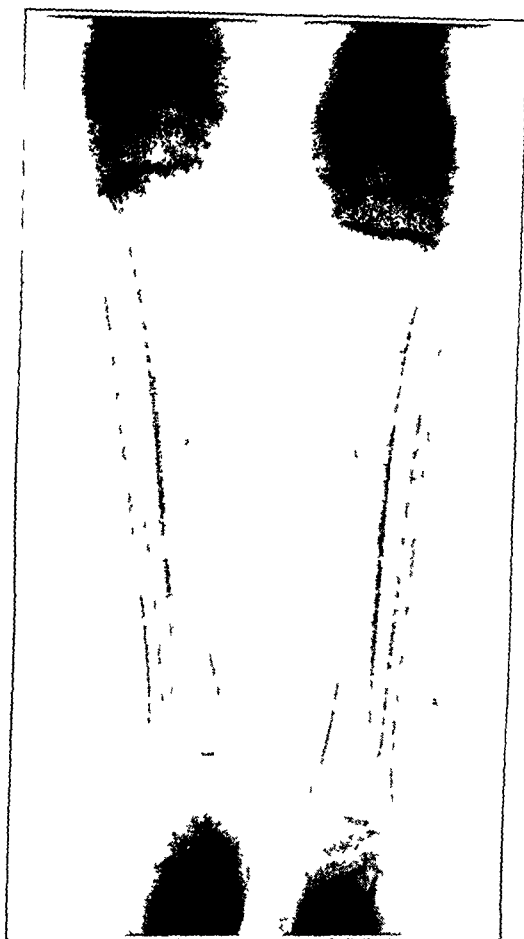


Fig 16—Roentgenogram of the bones of the legs in Case 14, made three months after those shown in Figure 15. The amount of atrophic change which has taken place may be noted.

whole are only slightly modified. The diameter of the shaft may be very slightly decreased. The length is not changed. The medullary canal is increased in diameter, producing a corresponding diminution in the thickness of the cortex, which after a long period of nonuse is reduced to a thin bone shell. The cancellous bone becomes much more porous, with fewer and thinner trabeculae. After a long period of nonuse, the compact bone of the shaft becomes porous. This

porosity explains the linear striae seen in the roentgenogram. Various degrees of bone atrophy due to nonuse during adult life are shown in Figures 1, 2, 3, 5 and 6.

#### A. CHARACTER OF CHANGES DURING PERIOD OF GROWTH

The changes in bone which result from lack of use during the growing period are of particular interest because two distinct processes are operating together, and the ultimate result is a marked change in the shape and contour of the whole bone. The bone is smaller both

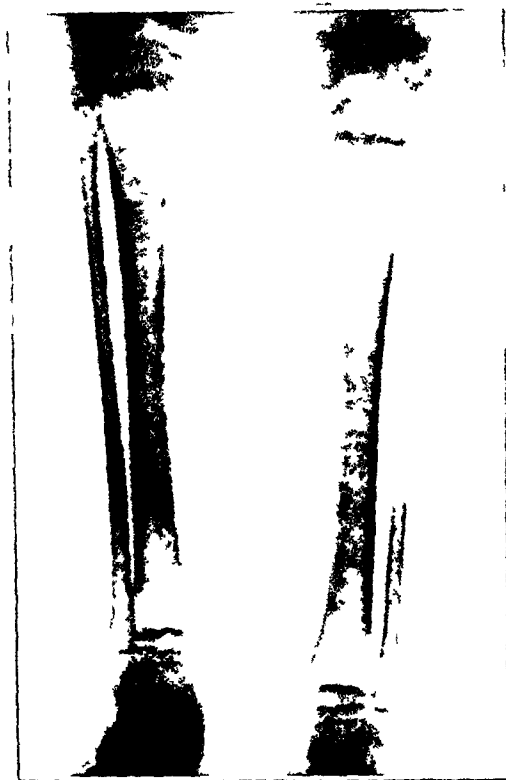


Fig. 17—Roentgenogram of the bones of the legs in Case 14, made fifteen months after those shown in Figure 15. The further progress of the atrophic changes may be noted. Compare the illustrations with the measurements recorded in the description of Case 14.

in length and thickness, the decrease in thickness is more noticeable than that in length. Furthermore, the diminution in thickness is more marked in the shaft than in the epiphysis, producing an effect of sudden enlargement at the epiphyseal regions. The thickness of the cortex relative to the diameter of the bone shows a change which is small compared with that seen in bone atrophy occurring during adult life. Comparative measurements of the thicknesses of the entire bones and

the diameters of the medullary canals show that the medullary canal of the nonused bone is always larger compared with the thickness of the same bone, although it may be actually smaller than the medullary canal of the corresponding bone of the used extremity. There may also be a difference in the shape of the cross section of the bones, comparing used with nonused, for example, the cross section of a normal used tibia is triangular in outline while the cross section of a tibia which has not been used during the growing period more nearly approaches a circle.

The various stages of the combined effect on bones of nonuse and growth are shown in Figures 17 and 18.

#### VI EFFECT OF NONUSE ON GROWTH OF BONE

The effect of lack of use on the process of growth of bones deserves special comment. That growth in length and thickness of bones takes place in complete absence of any use whatever is generally known. It is also well recognized that lack of use of one extremity during the period of growth will result ultimately in a short extremity. Two causes of this phenomenon are possible. The bones may grow at a decreased rate, or growth may stop earlier in the nonused extremity. The distinction and relative importance of these two factors have not been appreciated.

From the study of the cases of nonuse during the period of growth, it is clear that lack of use of an extremity results both in inhibition of growth and in an abnormally early cessation of growth in bones.

For example, in a case of anterior poliomyelitis in which there was complete lack of use in one extremity from four to nine years, there was a difference of 15 cm. in the lengths of the tibias. In another case of poliomyelitis in which there was a complete unilateral lack of use from four to twenty-five years, there was a difference in the lengths of the tibias of 34 cm. In a case of fracture of the femur in which the disability extended from eight to fourteen years, the tibias measured 29.8 and 32.3 cm., a difference of 2.5 cm. At this time the epiphyseal cartilages were present in both tibias. The same patient was studied again at the age of 15, at which time the epiphyseal cartilage was absent in the atrophied tibia and present in the used tibia. The tibias at this time measured 29.9 cm. and 33.3 cm., a difference of 3.4 cm., the increase in difference during the ages of 14 and 15 being due almost entirely to a cessation of growth in the tibia of the non-used extremity and a continuation of growth in the tibia of the used extremity.

The effect of the lack of use during the period of growth on the contour of bones was typically shown in Case 14, in which the bones

of the leg were studied for a period of thirteen months from the beginning of the nonuse. Following the onset of the paralysis the bones began to change in shape. The length increased. There was a continuous diminution in the diameter of the shaft. The diameters of the epiphyses continued to increase. The bone, therefore, in this period, changed in contour corresponding to that always found in bones of

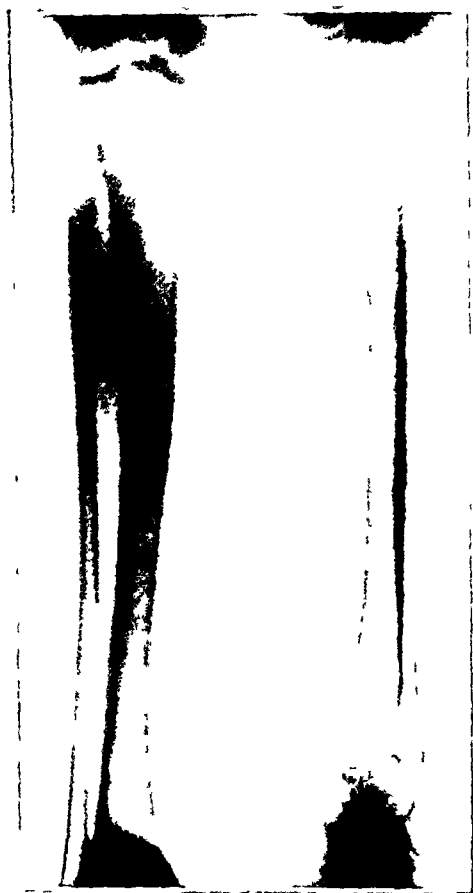


Fig. 18 — Roentgenogram of the bones of the legs in Case 15, a woman, aged 25, with complete paralysis of the left leg and partial paralysis of the left thigh as a result of an attack of acute poliomyelitis at the age of 4 years. The extremity had not been used. The marked changes in the bones of the left leg may be noted. Compare with Figure 19.

nonused extremities during the period of growth, namely, a small round shaft with relatively large flaring epiphyses (Figs. 14, 15, 16, 17 and 18).

#### VII. EFFECT OF NONUSE ON REGENERATION OF BONE

The effect of bone atrophy on regeneration of bone has been previously studied experimentally by us. It was found that bone atrophy

did not affect the process of bone regeneration. The proof of this conclusion has been confirmed by this clinical study. In Case 12, in which there was repeated fracture of the femur associated with extreme bone atrophy, each fracture united promptly when apposition of fragments was secured. In another case of extreme bone atrophy due to twelve years' lack of use of one lower extremity because of *tubes dorsalis* and a Charcot's hip joint, a fracture of the femur produced a large callus in four weeks.

#### VIII RECOVERY FROM BONE ATROPHY

An appreciation of the marked changes in the bones of an extremity which result from the lack of use of this extremity naturally leads to a consideration of the character and quantity of changes which may follow a reestablishment of function in the extremity. For the study of the process of recovery from bone atrophy, two groups of cases have been used. One group consisted of cases in which the history made it practically certain that the bones had previously been in a marked state of atrophy from nonuse. In these cases the bones were studied in comparison with a previous state presumed to have existed from our experience in other cases. In a second group of cases the bones were studied during the actual period of reestablishment of use. A period of two years is relatively short for a study of the second group of cases.

In Case 16 there was an attack of acute poliomyelitis at the age of 1 year, which resulted in a complete permanent paralysis of all the muscles of the leg. The patient, however, learned to walk during childhood and continued to use the extremity until she was observed at the age of 28 years. There was certainly a period after the onset of the paralysis in which the bones of the paralyzed leg were markedly atrophic. The end-results of establishment of use of the extremity, however, was that there were only slight differences in size and contour of the tibia.

In Case 11 there was lack of use of one lower extremity for a period of about eight months at the age of 6 years and a subsequent apparent, complete restoration of function. The patient was studied at the age of 12 years. At this time there was a difference in the size and contour of the tibia. The disease process was a "mild" osteomyelitis of the distal end of the femur.

In Case 12 the effect of one year's continuous use of an extremity in which the bones were atrophic from lack of use were studied in a boy between 14 and 15 years of age. During this period there was a marked increase in the thickness of the cortex of the shaft. The diameter of the shaft increased and the diameter of the medullary canal decreased. The thickness of the individual trabeculae of the

cancellous bone increased. There was, however, no evidence of an increase in the number of trabeculae per unit of area. In a case of tuberculosis of the knee in a woman, aged 30, who had not used the left lower extremity since she was 17 years old, roentgenograms revealed marked atrophy of all the bones of the extremity. The left knee was fixed in a position of flexion at 45 degrees (Fig. 20). The knee



Fig. 19—Roentgenogram of the bones of the legs in Case 16, a woman aged 28, with complete paralysis of the muscles of the right leg and a partial paralysis of the muscles of the right thigh as a result of an attack of acute poliomyelitis at the age of 1 year. The patient learned to use the extremity for walking, and it has been used continuously in spite of extensive paralysis. The bones of the right leg show atrophic changes, but these changes are much less marked than those found in Case 15, in which there was an equal amount of muscle paralysis but complete lack of use.

joint was excised and the patient was kept in a cast for a period of six months. Roentgen-ray examination revealed a further progress of the bone atrophy. The cast was removed and the patient began to use the extremity. Roentgen-ray examinations were then made at



intervals for a period of two years. During the last year the patient was walking on the leg with no other inconvenience than a stiff knee. After the reestablishment of a useful extremity there was a continuous change in the bones. The thickness of the cortex of the shafts of the bones increased to a marked degree. The trabeculae of the cancellous bone increased in thickness. There was, however, no evidence of the formation of new bone trabeculae (Fig 21). The thickness of the



Fig 20—Roentgenogram of the knee of a woman, aged 30, showing marked atrophic changes associated with tuberculosis of the knee joint. Compare the thickness of the cortex of the femur and the appearance of the cancellous bone with that shown in Figure 21.

cortex of the shafts of the bones still remained much less than in the corresponding bones of the extremity which had been continuously used since birth.

From the study of these and other cases, therefore, certain conclusions may be drawn as to the recovery from bone atrophy. If the lack of use is during the period of growth, there will be permanent changes in the size and shape of the affected bones. The reestablish-

ment or use will not result in a sufficiently increased rate of growth to make up for the loss which has occurred during the period of nonuse. It is obvious that to bring this about it would be necessary for a rate of growth above normal to take place. If the lack of use is during the adult period the shape and size of the bones are not materially changed and the reestablishment of use results in only an increase in the thickness of the existing parts of the bone. It is partic-

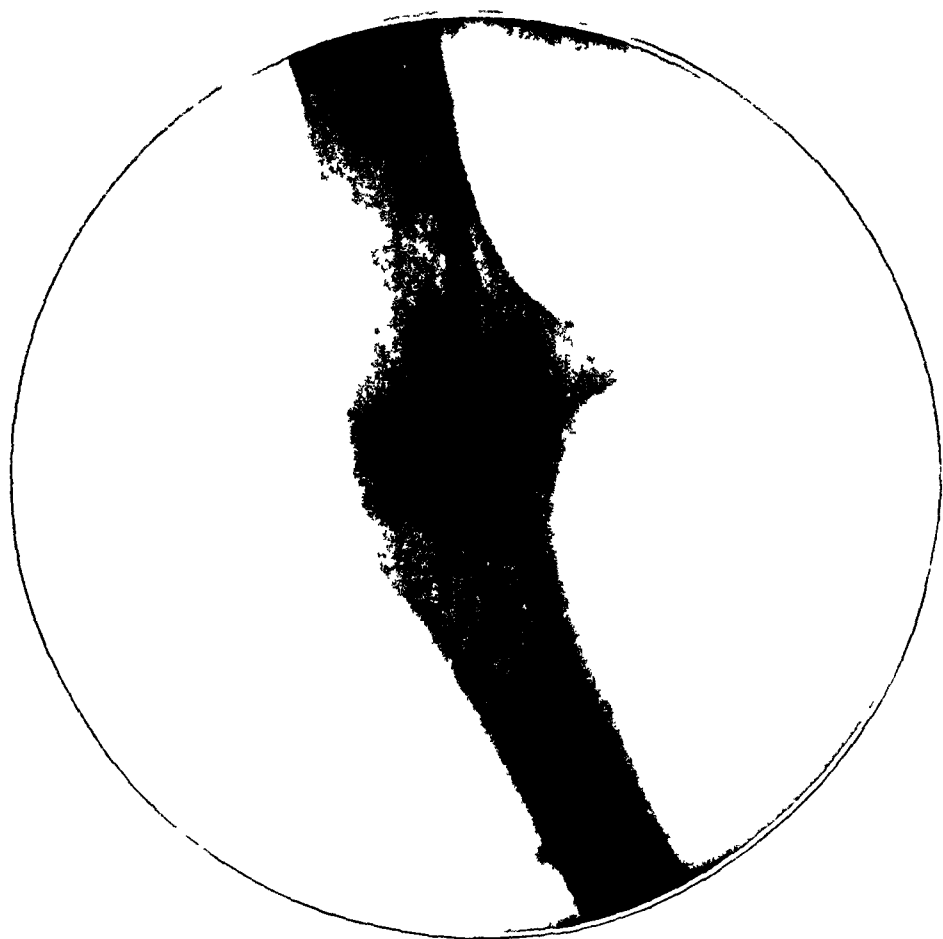


Fig. 21—Roentgenogram of the same knee shown in Figure 20, two years later, during which time the knee joint was resected and use of the extremity had been reestablished. The marked increase in thickness of the cortex of the femur and the increase in density of the trabeculae of the cancellous bone may be noted.

ularly interesting that lack of use results in a complete disappearance of part of the trabeculae of the cancellous bone. On reestablishment of use, these trabeculae are not reformed, but the existing trabeculae increase in thickness to a degree greater than normal. This results in the cancellous bone becoming a coarser network of struts of greater

thickness It is, therefore, often possible from examination of roentgenograms of bones to detect unmistakable evidence of previous periods of lack of use and to predict with some degree of accuracy the period in the patient's life during which the extremity was not used This statement is particularly applicable to instances in which the lack of use was unilateral

The changes in bones resulting from lack of use and the recovery from the changes after the reestablishment of use have in all instances already referred to occurred as a result of diseases of the extremities In a single instance in which a white woman, aged 48, was confined to bed for a period of one year incidental to repeated operations for intra-abdominal disease, it was found that all the bones of the extremities showed marked atrophy The fact that bone atrophy occurs as a result of confinement in bed is a matter of considerable clinical interest, particularly as it concerns children The material which has been studied has not been sufficient to permit drawing definite conclusions, except to state that long confinement results in atrophic changes in the bones

#### IX SUMMARY

It may be stated that these observations are evidence for the truth of a general theory of bone atrophy Bone atrophy and recovery from bone atrophy are manifestations of the function of bone cells to produce bone matrix, which is in whole or in part distinct from the function of the bone cells to regenerate themselves Bone atrophy and recovery from bone atrophy are processes which are not necessarily associated with cell death or cell proliferation Regeneration is a process which is directly the result of cell multiplication

# EXPERIMENTAL STUDY OF THE HEALING OF FRACTURES\*

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This study was undertaken to clear up several obscure points in the process of healing of fractures but chiefly to ascertain the exact role assumed by the periosteum. Three sets of experiments were performed on cats and in all the humerus was fractured.

In the first series the humerus was fractured by direct external violence, applied laterally. I used my thumb as a fulcrum and, in case the bone was too tough to be broken thus, I broke it over the edge of the table. In the second series I made a lateral incision, dissected the tissues down to the periosteum, divided the periosteum circularly, fractured the bone with a Gough saw or Liston bone forceps and sutured the wound. The third series was similar to the second except that the periosteum was simply slit longitudinally to give access to the bone.

Complete narcosis under ether was employed and in the open operations due attention was given to asepsis. The cats were killed at intervals. Cats 16 and 17 with chloroform the rest with illuminating gas.

The fractured bone, with its periosteum, was removed shortly after death, and was fixed in from 4 to 10 per cent liquor formaldehydi, and was decalcified in a 5 per cent solution of nitric acid. In the case of three cats (Cats 10, 11 and 12), the bones were placed immediately in nitric acid solution by mistake without previous fixation. All but these three were roentgenographed before decalcification. Each specimen was divided longitudinally, was run up through the alcohols and ether, and was mounted in celloidin. Sections were cut and stained with hematoxylin and eosin and with the Unna and van Gieson stains.

## PROTOCOL OF EXPERIMENTS

### FIRST SERIES SIMPLE FRACTURE BY DIRECT VIOLENCE

EXPERIMENT 1—Cat 1, a large sized adult animal was killed with illuminating gas four days after the fracture. Marked ecchymosis was revealed when the cat was skinned. There was marked displacement of the fragments with overriding. The bone was removed together with the surrounding tissues and was sectioned longitudinally. One half the specimen was decalcified, embedded cut and stained.

The stained slide showed no overriding but slight lateral displacement. The bones were situated end to end. The marrow canal of one was open but the knife had caught the other bone obliquely so that its cortex shut off its canal on

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\* From the laboratory of surgical pathology Stanford University

the slide In the tissues about the ends of both bones was much fibrin, and a mass of fibrin in which were one or two bone spicules separated the two The surrounding tissues showed cellular infiltration

*Fragment with the Open Canal*—The lymphoid marrow appeared as a band on each side of the canal, plugging up the end, with the fatty marrow in the center A layer of fibrin also lay partly across the end of the canal The periosteum showed two distinct layers of about equal thickness, an inner, or cellular, and an outer, or fibrous layer It ended a short distance from the fractured extremity, leaving the cortex bare The outside of the cortex on one side was irregular and notched, and showed an irregularity of staining reaction, as if it were already being attacked, and it looked as if the formation of Howship's lacunae were beginning, but no giant cell osteoclasts were in evidence This observation, if correctly made, would indicate that the so-called osteoclasts were not the cause of the osteoclasts, but the result

*Fragment with the Closed End*—This contained lymphoid marrow The cortex was covered with periosteum in two distinct layers, the inner increasing markedly in thickness toward the end of the bone The marrow canal contained many bone trabeculae

*Summary*—The ends of the fragments were buried in fibrin There was an aggregation of lymphoid marrow at the circumference of the marrow canal of one fragment The periosteum lay in two distinct layers

EXPERIMENT 2—Cat 2, a full grown cat, was killed with illuminating gas, eight days after the fracture There was no sign of epiphyseal cartilage in the head of the humerus Less ecchymosis was present than in the first cat, and that only about the elbow and fore leg There was much overriding of the fragments The bone was removed with the surrounding tissue

Two sets of slides were made Each set showed one bone cut longitudinally, with its marrow canal open on the end, and the other cut diagonally, with its marrow canal closed by bone Evidently, each fragment was cut fairly in one set of slides One of the fragments showed splintering The two fragments overlapped Remains of hemorrhage were present at their ends The ends were surrounded by granulation tissue, and this granulation tissue ran for a very short distance into the marrow canal as if to plug it up The tips of the cortex showed well marked so-called rarefying osteitis

The behavior of the periosteum was peculiar At some distance from the fracture, it left the bone, the space between the two gradually widening, and showing distinct evidence of new bone trabeculae The periosteum of one of the fragments was notable because of the presence in it, or in its immediate vicinity, of well marked hemorrhage This line of hemorrhage made the course of the periosteum more distinct It was not diffuse, but followed the periosteum closely At a short distance from the broken end the fibers of the periosteum diverged from one another, and, just before the end of the bone was reached, they were lost in the granulation tissue No bone trabeculae appeared within the cortex

The foregoing holds good for one fragment—the clean cut one The splintered fragment showed a rather different picture The periosteum was not so easily recognized, and no bone trabeculae appeared under it, *except at some distance from the end* New bone trabeculae were abundant on the inside of the cortex

*Summary*—Granulation tissue surrounded the bone ends There was beginning bone formation on the outside of the cortex of one fragment and on the inside of the cortex of the other



Fig 1—*A* normal humerus of Cat 1, *B* fractured humerus of Cat 1 after removal

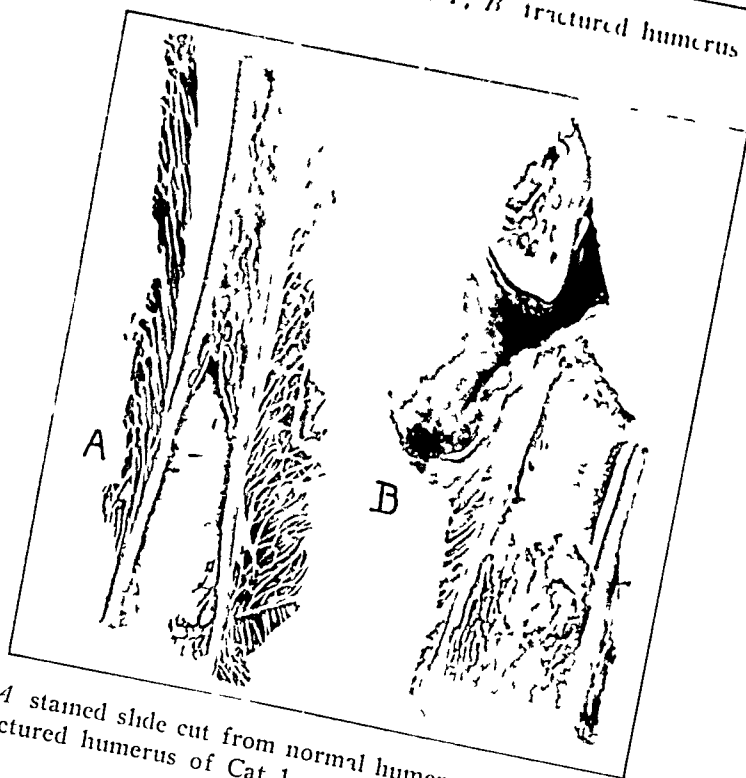


Fig 2—*A* stained slide cut from normal humerus of Cat 1, *B*, stained slide cut from fractured humerus of Cat 1

EXPERIMENT 3—Cat 3 was killed with illuminating gas, thirteen days after the fracture. There was no ecchymosis. Thickening was present about the seat of fracture, but apparently there was less overriding than in Cats 1 and 2. There was free motion. The bone was removed with the surrounding tissue, and sectioned longitudinally.

One of the bones had been caught by the knife in such a way that it appeared as a small point of bone slightly overlapping the irregular fractured end of the other fragment. The two fragments were bound together by a mass of fibrous tissue and cartilage, and in this fibrous and cartilaginous tissue, the formation of bone trabeculae was well advanced. Small spicules of bone, evidently fractured at the time of operation, could be seen here and there. The new trabeculae were especially abundant on the outside of the cortex, immediately beneath the periosteum. They capped the pointed fragment,

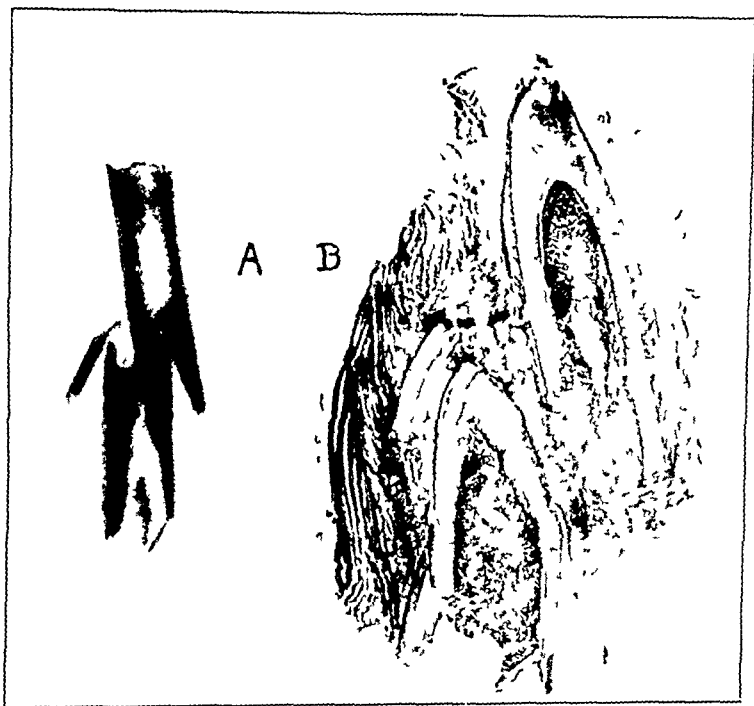


Fig 3—A, fractured humerus of Cat 2, B, stained slide cut from fractured humerus of Cat 2

and, on the other fragment, they were especially numerous on the far side of the cortex. In the latter fragment the formation of internal callus was beginning, not on the inner aspect of the cortex but in the marrow canal itself. One small fractured spicule of bone showed the formation of new trabeculae on its borders.

*Summary*—The fragments were bound together by fibrous and fibrocartilaginous tissue, in which new bone was forming. New trabeculae were especially numerous on the outside of the cortex. There was some new bone formation within the canal of one fragment—so-called internal callus.

EXPERIMENT 4—Cat 4 was killed with illuminating gas, sixteen days after fracture. There were slight remains of ecchymosis, thickening about the seat of fracture and marked overriding. The bone was removed with the surrounding tissue, and sectioned longitudinally.

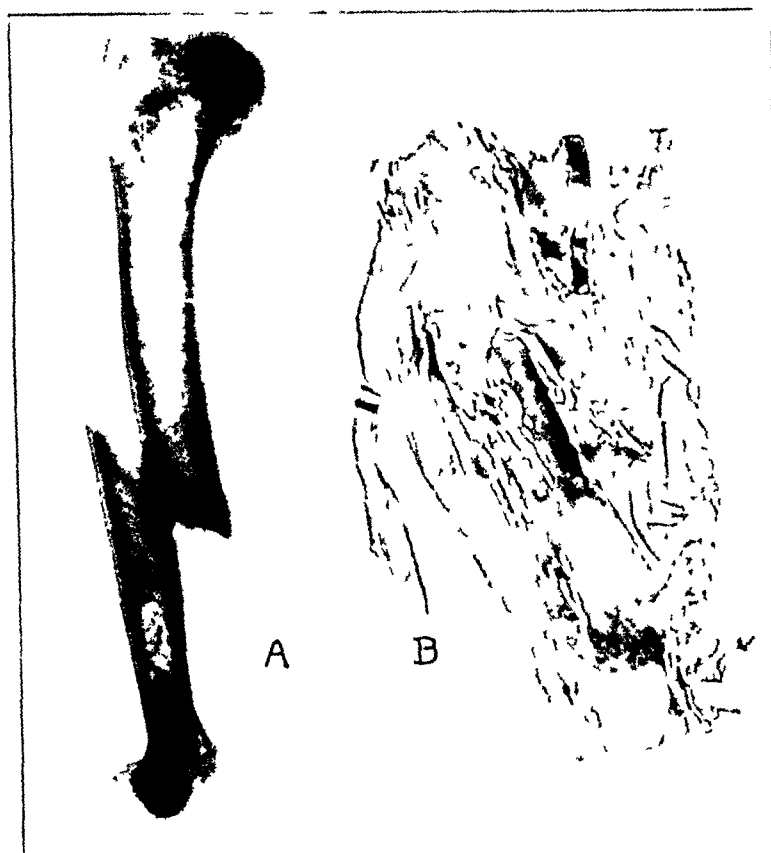


Fig 4—*A*, fractured humerus of Cat 3, *B*, stained slide cut from fractured humerus of Cat 3

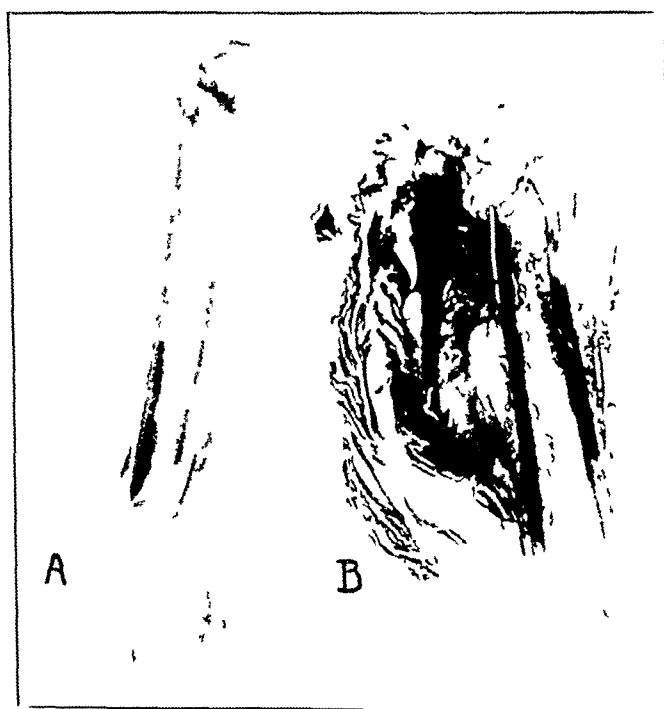


Fig 5—*A*, fractured humerus of Cat 4, *B*, stained slide cut from fractured humerus of Cat 4



*Examination of Stained Slide*—The knife had caught one fragment fairly, but the other fragment evidently was split. The two fragments had overridden about 1.5 cm. Dense bone almost shut off the marrow canal of the fragment caught fairly. This was evidently due to diagonal sectioning, because it was not new bone. At the end of each fragment was a mass of fibrous tissue containing rifts. Almost capping one fragment and extending well over on its far cortex was a large mass of cartilage. A much smaller area appeared on its near cortex, about a centimeter from its fractured end, and a still smaller piece on the outside of the far cortex of the other fragment, about 0.5 cm. from its fractured end. Cartilage and fibrous tissue thus united the two fragments fairly firmly.

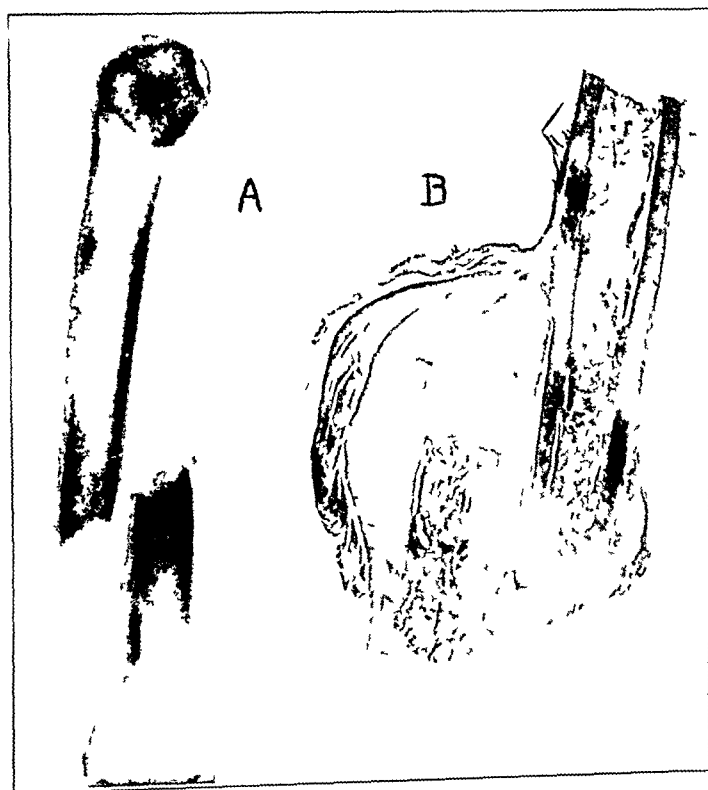


Fig 6—*A*, fractured humerus of Cat 5, *B*, stained slide cut from fractured humerus of Cat 5

New bone trabeculae were forming on the outside of the cortex of both fragments, springing from it, as it were, not only in the masses of cartilage but also in and under the periosteum. Bone trabeculae were also forming on the inside of the cortex—internal callus.

*Summary*—The fractured bones were united by cartilage and fibrous tissue, in which new bone trabeculae were forming. There were indications of internal callus in the marrow canals of both fragments, but this internal callus apparently played no effective part in the union.

**EXPERIMENT 5**—Cat 5 was killed with illuminating gas, twenty days after fracture. There was considerable thickening at the seat of fracture with a little motion.

*Examination of the Stained Slide*—The two fragments, overlapping about 6 or 8 mm and separated by an interval of about 3 mm, were bound together

by a fusiform mass of fibrous tissue containing large and small islands of cartilage. Close to the bone cortex in places ossification was beginning in this mass of new tissue only to a minimal extent on one of the two apposed cortices but to a much greater extent on the outside of the far cortex of each fragment. In the latter situation, intracartilaginous bone formation between the cortex and the periosteum was active and well advanced. New bone trabeculae were abundant in the marrow canal of each fragment in the neighborhood of its fractured extremity—the so-called internal callus. Continuous with the end of one cortex only new bone was being built up, apparently out of the fibrous tissue which embedded the end of the fragment. There were small pits in the welding fibrous tissue.

*Summary*—The overlapping bones ended in a mass of fibrous tissue and cartilage, which surrounded them like a plumber's wood joint. New bone was



Fig 7—*A*, fractured humerus of Cat 6, *B*, stained slide cut from fractured humerus of Cat 6

being built up in this fibrous tissue and cartilage. Internal callus was present in each marrow canal, but seemed to play no essential part in the process of healing.

**EXPERIMENT 6**—Cat 6, a small, apparently young cat, was killed with illuminating gas, twenty-four days after fracture. The fragments showed marked overriding, and had no stability.

*Examination of the Stained Slide*—The fragments overlapped about 1 cm. The end of one fragment was open, the end of the other was closed off by bone, evidently the bone of the old cortex caught by the knife at an oblique angle. Between the two fragments lay a mass of cartilage, fibrocartilage and fibrous tissue. Fibrous tissue lay over the open end of one fragment, a cap of cartilage over the closed end of the other. In these two situations, new bone formation was beginning. It was also beginning in the cartilage in the angle where the periosteum left the cortex of one fragment to pass across to that

of the other, and externally on the cortex on the far side of one fragment. No indication of internal callus was present. A small fragment of bone lay at a short distance from the end of the closed fragment. It was probably part of a splinter. *On it new bone was being formed.* A large cleft or series of clefts ran from the end of one fragment, part way over to the other fragment in the fibrous tissue between the two bones.

*Summary*—The bones were united by fibrous tissue containing masses of cartilage, especially in the immediate vicinity of the cortices. The marked instability, together with the presence of the rifts in the fibrous tissue, indicated that perhaps a false joint was in process of formation.

EXPERIMENT 7—Cat 7, a small, probably young animal, was killed with illuminating gas, twenty-eight days after the fracture. There were marked overriding of the fragments and free motion.

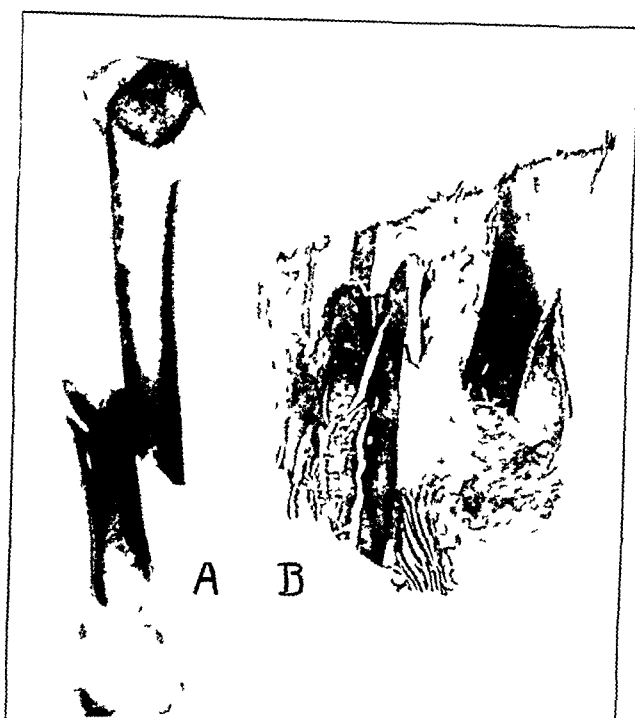


Fig 8—*A*, fractured humerus of Cat 7, *B*, stained slide cut from fractured humerus of Cat 7

*Examination of the Stained Slide*—The overlapping fragments were bound together by a dense mass of fibrous tissue and fibrocartilage which extended well over the end of each fragment. Hyaline cartilage was also present in this mass, especially near the cortex. The end of one fragment was comminuted. In this hyaline cartilage, close to the cortex, bone formation had begun, not only on the two cortices facing each other, but also to a lesser extent on the cortex on the far side. A few new trabeculae were visible in the marrow here also apparently being formed from cartilage and fibrocartilage—the so-called internal callus. The new bone on the outside of the far cortex was forming under the fibrous periosteum in a sort of spindle shaped callus.

*Summary*—There was cartilaginous callus, with bone formation beginning close to the cortex.

EXPERIMENT 8—Cat 8, a very large full grown cat, was killed with illuminating gas, thirty-five days after fracture. Considerable overriding of the fragments was present, and a little motion. Union seemed to be well advanced.

*Examination of the Stained Slide*—The overriding of the fragments amounted to about 1.5 cm. The marrow canal of one fragment was open, that of the other was closed off by bone, but whether this was new bone or the old cortex cut obliquely it is impossible to say. A mass of cartilage lay between the two overriding fragments, and over the end of them. This cartilage was being ossified from each cortex. The ossification had proceeded to such an extent that fairly well formed marrow lay among the new trabeculae. Considerable internal callus was seen in the open ended fragment which appeared to

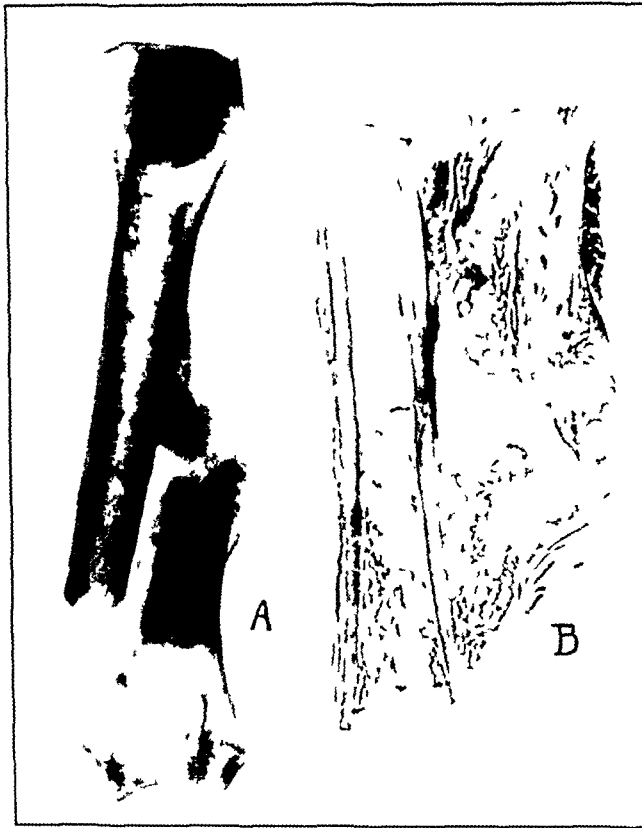


Fig 9—A, fractured humerus of Cat 8. B, stained slide cut from fractured humerus of Cat 8.

have no connection with the external callus. No evidence appeared of any effort at remodeling the fragments, except in the closed off end of one, where new blood vessels apparently were pushing into the bone, and causing an absorption, but without any evidence of so-called rarefying osteitis.

The periosteum had suffered in the cutting, but it could be fairly well traced from the far side of the cortex of one fragment, covering the new bone in that situation, and then across the new cartilage and bone formation almost to the other fragment. The periosteum on the far side of the other cortex was practically without reaction and ended shortly after leaving the bone, from which it had been stripped for about a centimeter. This was probably due to the cutting of the block.

*Summary*—The fragments were fairly firmly welded together by a cartilaginous callus in which bone formation was well advanced. The periosteum did not appear to play any active part in the union.

*EXPLRIMENT 9*—Cat 9, a large, full grown animal, was killed with illuminating gas, forty-two days after the fracture. There was thickening about the seat of the fracture, and apparently firm bony union.

*Examination of Stained Slide*—The two fragments, overriding about 1 cm, were closed off at their ends by old bone. This closure was evidently due to the obliquity of the cutting knife. They were united by a mass of cartilage, in which new bone formation was fairly well advanced and over which periosteum stretched. Bone formation was especially noticeable close to the cortex.

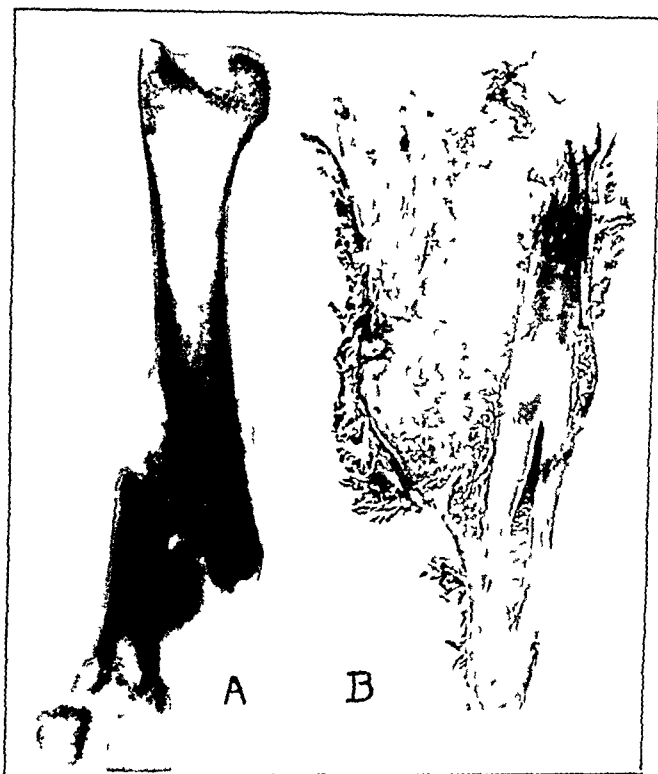


Fig 10—4, fractured humerus of Cat 9, B stained slide cut from fractured humerus of Cat 9

in the angle where the stripped-up periosteum left it to pass over to the other bone, but the periosteum itself was apparently not taking any active part in the bone formation. The mass of ossifying cartilage extended over the tips of the fragments. No evidence of any internal callus was seen.

*Summary*—The overriding fragments were firmly welded by a mass of cartilage well advanced in ossification. The periosteum did not seem to be taking any part in the process.

*EXPERIMENT 10*—Cat 10, an adult animal, was killed with illuminating gas, forty-nine days after fracture. Marked lateral displacement was present, and more than a centimeter of overriding. One sharp fragment seemed to have punctured the periosteum. The fragments moved a little on each other.

*NOTE* Instead of being put in liquor formaldehydi, the specimen was put in 5 per cent nitric acid immediately, by mistake and remained in it for four weeks.

*Examination of Stained Slide*—The fragments overrode to the extent of about 15 cm. The end of each was closed off by dense fibrous tissue, underneath which was a rather thin layer of newly formed bone. In the fibrous tissue were rifts. In the central marrow canal of one bone and on the inner aspect of the cortex of the other, new trabeculae were present—an indication of internal callus.

The two fragments were bound together by a dense tissue, part of which was fibrous and the rest looked like cartilage under low power magnification, but contained no cartilage cells that could be distinguished. New bone trabeculae were being formed in this tissue at its junction with the cortex.

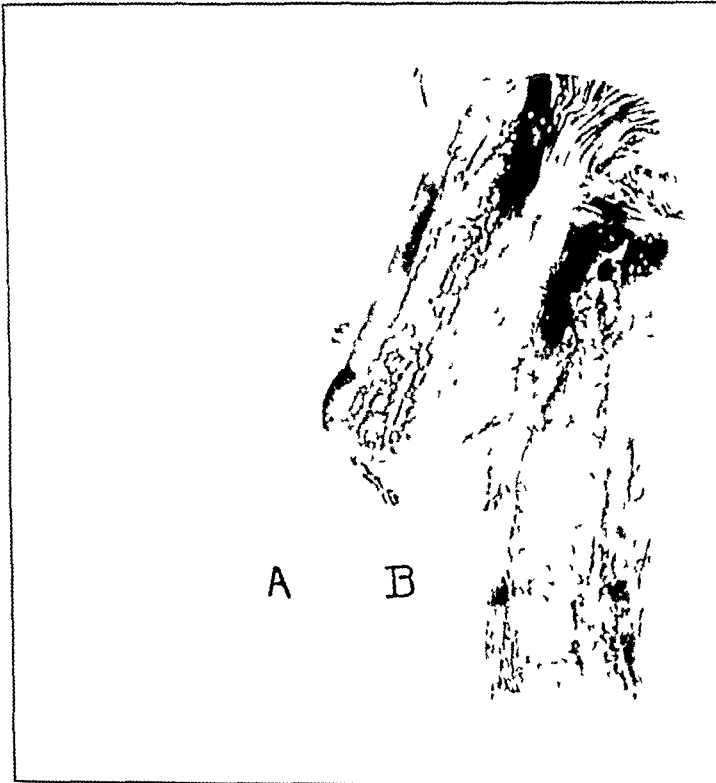


Fig 11—*A* fractured humerus of Cat 10, subsequent to decalcification, *B* stained slide cut from fractured humerus of Cat 10

*Summary*—There was fibrous and cartilaginous callus in which bone formation was advancing. The state of the specimen precluded arriving at finer details.

**EXPERIMENT 11**—Cat 11, a small animal but apparently an adult, was killed with illuminating gas, fifty-seven days after the fracture. There was marked deformity at the seat of the fracture but apparently solid bony union.

**NOTE**—Instead of being put into liquor formaldehydi, the specimen was put into 5 per cent nitric acid by mistake and remained in it for three weeks.

*Examination of Stained Slide*—The ends of both fragments were pointed, bone shutting off their marrow canals, but this was probably an artefact, caused by the angle of the microtome knife. They were welded together by a fusiform mass of cartilage well advanced in ossification. The fragments themselves were separated by an interval of about 0.5 cm. Over the fusiform mass the peri-

osteum stretched. The new bone was especially abundant in the immediate vicinity of the cortex, and ossification was also well advanced in the angle where the periosteum left the bone at a short distance from its end, but the periosteum itself did not appear to be taking any active part in the new bone formation. In the cartilage, blood vessels could be seen, giving a picture analogous to that seen in an epiphysis when ossification is taking place. The mass of bone and cartilage lay between the bones, as well as about their ends. There was no indication of any internal callus.

*Summary*—Firm union had been accomplished by ossification of cartilaginous callus. In this union the periosteum appeared to be taking no active part.

**EXPERIMENT 12**—Cat 12, a very large animal, was killed with illuminating gas, sixty-three days after the fracture. Considerable deformity was present at the seat of fracture, with solid union.

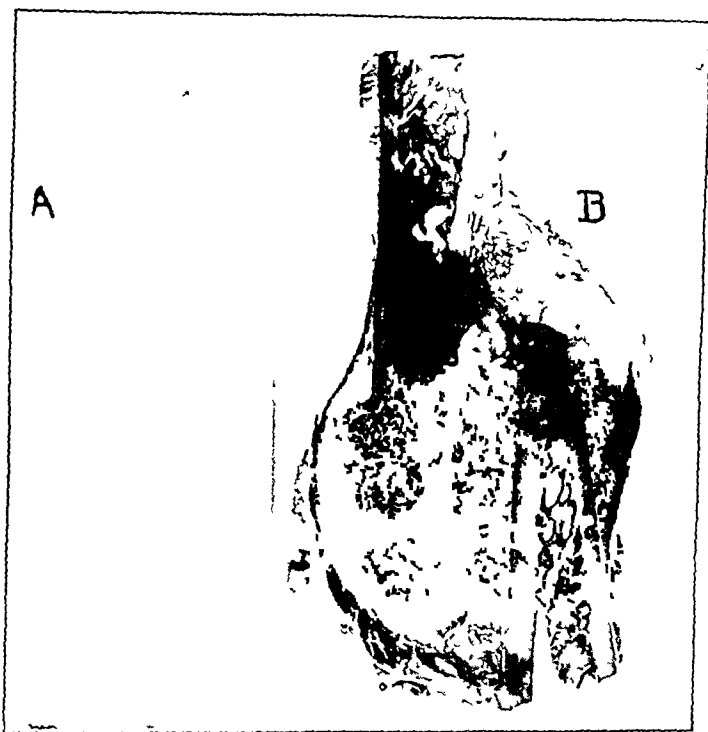


Fig 12—*A*, fractured humerus of Cat 11, subsequent to decalcification, *B*, stained slide cut from fractured humerus of Cat 11.

**NOTE** Like the two preceding, this specimen also was put into 5 per cent nitric acid immediately, by mistake, and remained in it for three weeks.

*Examination of Stained Slide*—The two fragments overlapped for about 2 cm. The end of one had been caught obliquely by the microtome knife so that the cortex appeared to close the end of the central marrow canal. The marrow canal of the other fragment had been closed off by new bone.

The ends of the fragments, not in close apposition, were united by new bone and by partly ossified cartilage, and the cortex of each fragment contiguous to this uniting tissue was opening up, that is, was being converted into spongy bone, so that evidently the marrow canals of the two fragments already communicated through the bone meshwork. No evidences of so-called

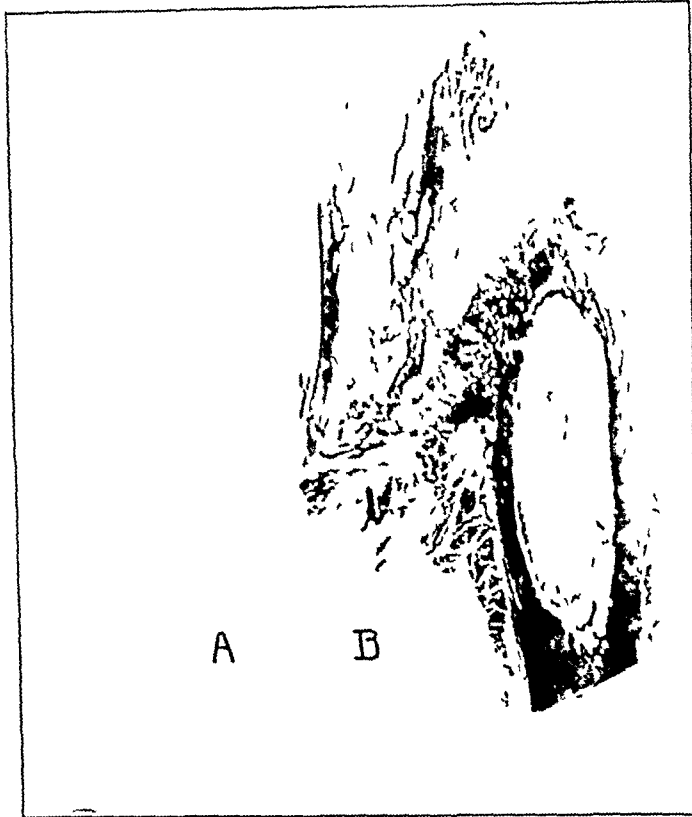


Fig 13 — *A*, fractured humerus of Cat 12, subsequent to decalcification, *B*, stained slide cut from fractured humerus of Cat 12

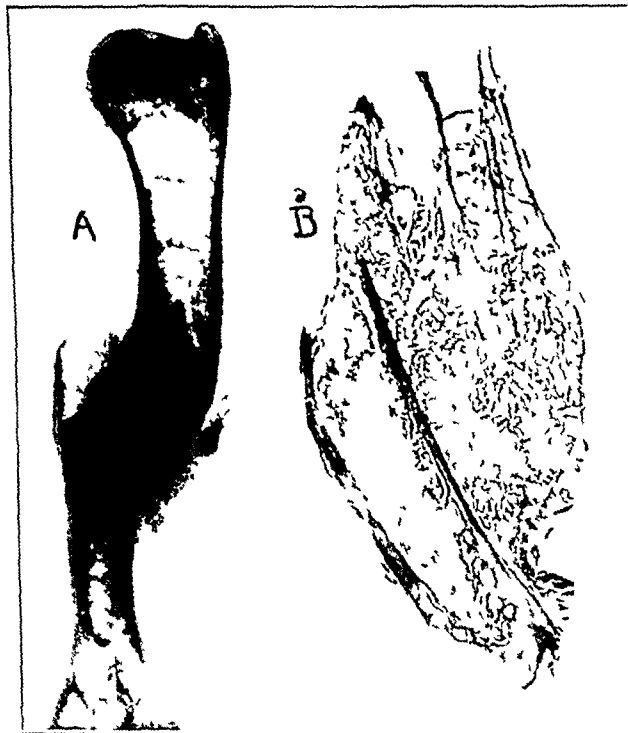


Fig 14 — *A*, fractured humerus of Cat 13, *B*, stained slide cut from fractured humerus of Cat 13



rarefying osteitis were present, however. In the immediate vicinity of this part of the cortex, the marrow canal of one fragment showed the new bone trabeculae of the internal callus, but not the marrow canal of the other. All about the closed end of the other fragment, bone trabeculae were forming in fibrous tissue.

*Summary*—New bone from cartilage and fibrous tissue united the fragments laterally. There was rearrangement of the bony architecture. The role of internal callus was insignificant. The role of the periosteum was hard to distinguish.

EXPERIMENT 13—Cat 13, a large animal, was killed with illuminating gas, seventy-one days after the fracture. Marked thickening was present at the site of fracture, with overriding and firm bony union.

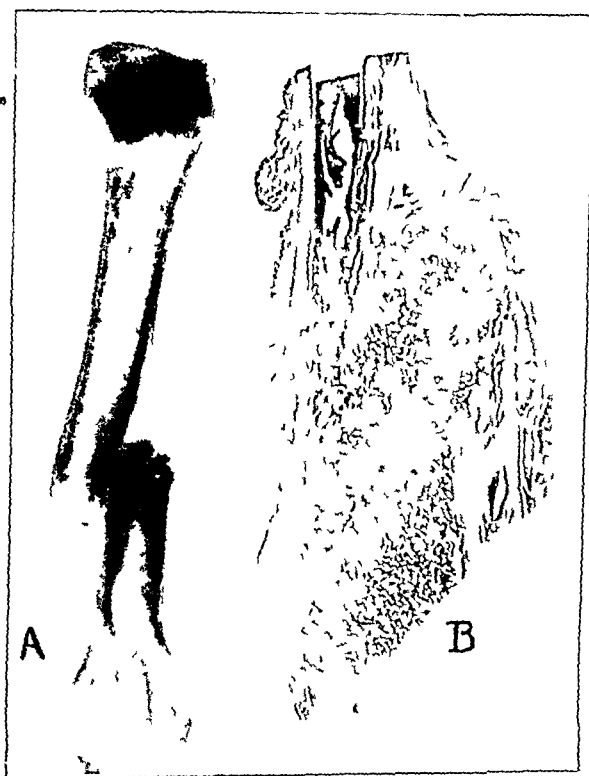


Fig 15—*A*, fractured humerus of Cat 14, *B*, stained slide cut from fractured humerus of Cat 14.

*Examination of Stained Slide*—The fragments overrode for about 0.5 cm and were separated laterally about the same amount. They were united laterally by a mass of newly formed bone, some of which was not yet completely ossified. No cartilage could be detected in this bone. The new bone covered the end of each fragment like a cap, and apparently its blood vessels communicated with those in the marrow canals in the fragments.

*Summary*—New bone united the overlapping fragments laterally.

EXPERIMENT 14—Cat 14, a rather small animal, was killed with illuminating gas, seventy-seven days after the fracture. There was overriding of the bone ends, with firm union.

*Examination of Stained Slide*—The two fragments, overlapping for about a centimeter, had been firmly united by a mass of bone developed from cartilage, laid down between their overlapping cortices. The bone development was not yet completed, because a large amount of cartilage was still mixed up with the bone tissue, and rearrangement of the bone trabeculae was still progressing. Owing to the fact that one fragment had been caught obliquely by the microtome knife, its architecture could not be well made out, but study of the end of the other fragment demonstrated that the end of the cortex facing the first fragment had been torn down, and that spongy and irregular bone had replaced it, showing that its presence was no longer necessary. The cortex on the far side near its end had suffered slightly and in one limited area was being replaced



Fig 16—*A*, fractured humerus of Cat 15, *B*, stained slide cut from fractured humerus of Cat 15

by spongy bone. In this exact place new bone had been built up beneath the periosteum on the outside of the cortex.

*Summary*—The overlapping ends of the fragments were united firmly by new bone, chiefly developed from cartilage. The architecture of the cortex was being rearranged.

#### SECOND SERIES

With Cat 15 begins a new series of operations. An incision was made on the lateral aspect of the fore leg and the dissection was carried to the periosteum. This was divided circularly, and the bone

was fractured either with a Gigli saw or Liston bone forceps. The wound was then sutured, and a sterile dressing was applied. Infection occurred only once in the series.

EXPERIMENT 15—Cat 15, a large, full grown animal, was killed with illuminating gas sixty-five days after the fracture. An incision had been made down to the bone, also an attempt, not very successful, had been made to divide the periosteum. The bone had been fractured with Liston bone forceps. Deep and superficial sutures had been made and collodion applied.

Free motion was present at the seat of fracture, with overriding. There was no sign of union.



Fig 17—*A*, fractured humerus of Cat 16, *B*, stained slide cut from fractured humerus of Cat 16.

*Examination of Stained Slide*—The specimen had been caught at an unsatisfactory angle by the microtome knife. One fragment showed its medullary canal, and in this canal new bone trabeculae could be seen. The other fragment showed the central medullary canal only at its extreme end, and here the new bone trabeculae were so abundant that they practically shut off the end of the canal. At the end of one cortex of the latter fragment, a cap of new bone was being formed out of cartilage. Each fragment showed new intracartilaginous bone formation, generally in irregular knobby areas on the outside of each cortex, but there was no bridge of bone and cartilage connecting the two fragments. On the outside of the cortex, the regular strips of new periosteal bone were missing, which were evident in the first series of operations. Irregular fibrous tissue covered the end of each fragment and bound the two

fragments together, but, except immediately contiguous to the cortex, no new bone or cartilage could be discerned in this fibrous tissue. Through this connecting tissue and running across diagonally from bone to bone was a large cleft, or, better expressed, a series of clefts. The walls of this cleft were irregular and in places showed well marked villous appearance, but no definite cartilage.

*Summary*—There was formation of a false joint. The bones were united by fibrous tissue, and in this fibrous tissue was a series of rifts.

**EXPERIMENT 16**—Cat 16, a large adult cat, was killed with chloroform, eleven days after the fracture. An incision was made as in Cat 15. Dissection was carried down almost to the bone. An aneurysm needle was passed about the bone, including some muscle tissue and the periosteum. A Gigli saw passed in the track of the aneurysm needle divided the bone and periosteum.

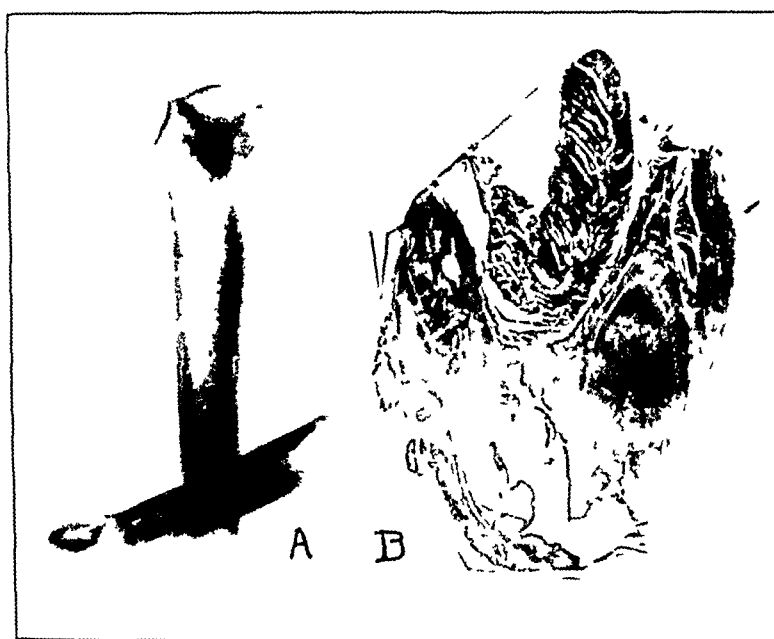


Fig 18—*A*, fractured humerus of Cat 17, *B*, stained slide cut from fractured humerus of Cat 17

The wound became infected, and the cat was killed. The old wound was opened, revealing a large subcutaneous pocket of pus. Whether or not this pus pocket communicated with the fracture was not determined. The fragments had overridden noticeably. The distal end of the proximal fragment was down almost level with the condyles. The fragments moved freely on one another, and showed no sign of union.

The bones were removed, together with the surrounding tissues, were washed and then put into liquor formaldehydi.

*Examination of Stained Slide*—The ends of the bones overlapped about 15 cm, and were bound together by a dense hyaline, fibrous tissue which appeared to be metamorphosing into cartilage, although no distinct cartilage cells could be seen in it. The marrow canals of both fragments were open. That of one fragment was closed off by the hyaline, fibrous tissue, but as to the other canal nothing could be said, for everything had been cut by the

knife, down to the end of the bone. In the fibrous tissue, and running almost parallel with the bones but slightly obliquely, was a distinct rift, as if a joint were being established. In the fibrous tissue on the apposed cortices, new bone formation was beginning, but on the cortices on the far side, no new bone was present nor was there any evidence of the formation of an internal callus.

*Summary*—There was probable infection. Apparently a false joint was in the process of formation.

*EXPERIMENT 17*—Cat 17 was killed with chloroform, fifteen days after the fracture. The operation was the same as that performed on Cat 16 except that the saw broke during the operation, and the division of the bone was completed with Liston bone forceps.

The wound broke down and suppurated, necessitating chloroforming the cat after fifteen days. The bones were removed, with the surrounding tissue they had overridden, and the distal end of the proximal fragment was at about the level of the condyles. There was no sign of union, and very free motion.

*Examination of Stained Slide*—Both fragments had been caught at an angle by the microtome knife, so that exact details were hard to determine, but no union had taken place, and apparently the only effort at it was represented by a small amount of external callus on each cortex of each bone. There was an open space between the fragments lined by a tissue that had very much the appearance of synovial membrane.

*Summary*—Suppuration was present, and there was practically no attempt at union.

*EXPERIMENT 18*—Cat 18 was killed forty-five days after the fracture. There was circular division of the periosteum as with Cat 16, with division of the bone by a Gigli saw. When the cat was killed the fragments were apparently firmly united in the presence of much callus.

*Examination of Stained Slide*—The two fragments overlapped about 15 cm. They were about 1 cm apart laterally, and their marrow canals were closed off by a very thin layer of new bone. This thin layer of bone was evidently being thickened up, for further intracartilaginous bone development could be seen going on outside of it. One fragment showed a few scattered trabeculae in its medullary canal, but neither fragment showed any internal callus in the shape of new bone on the inside of the cortex. There was practically no bone formation on the far side of the external aspect of either cortex. The two fragments, about a centimeter apart, were joined by a dense mass of new bone and cartilage, that is, by cartilage in which new bone formation was well advanced in the vicinity of the cortices, unossified cartilage separating the two strips of newly formed bone. Dividing this strip of cartilage through its whole extent, and running parallel to the bone, was an irregular but well defined slit or rift. This rift, bounded as it was by cartilage backed up by bone, and with its extreme ends closed off, gave an appearance strikingly analogous to that of a regular joint.

*Summary*—There was formation of a new joint by means of a rift in the cartilaginous callus joining the fractured bones laterally.

*EXPERIMENT 19*—Cat 19 was killed sixty-three days after the fracture. The same operation was performed as on Cat 16—circular division of the periosteum and bone with the Gigli saw. When the cat was killed, firm bony union with marked overriding was apparently present.

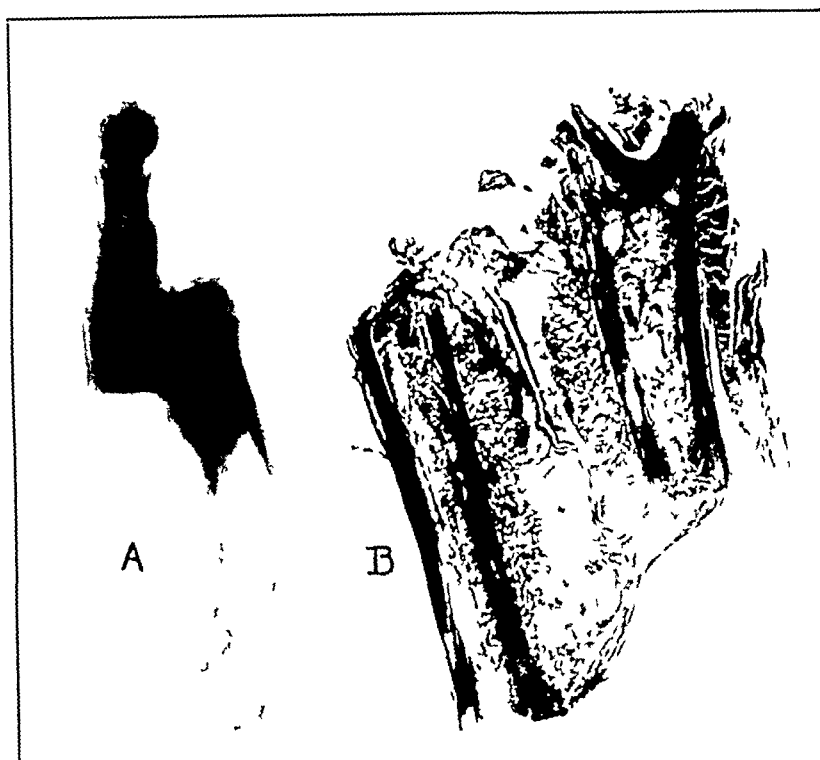


Fig 19—*A*, fractured humerus of Cat 18, *B*, stained slide cut from fractured humerus of Cat 18



Fig 20—*A*, fractured humerus of Cat 19, *B*, stained slide cut from fractured humerus of Cat 19

*Examination of Stained Slide*—The ends of the bones had not overridden at all, but there was some lateral displacement at the seat of fracture. The ends of the bones had been caught obliquely by the microtome knife, so that it was impossible to say whether or not their marrow canals were still open. They were firmly united by a mass of new bone which had been formed from cartilage and was densely spongy in its texture. This new bone was continuous with that of the cortex in the neighborhood of the end of each fragment, as well as with the very end of each fragment itself.

*Summary*—There was firm union of the fragments by bone developed from cartilage.

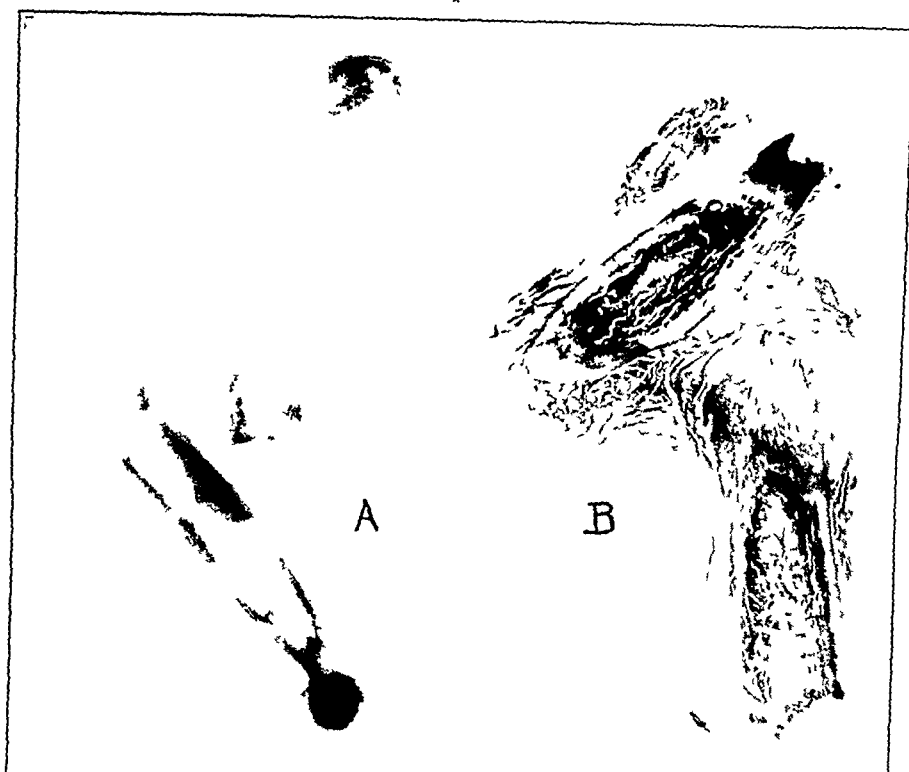


Fig 21—*A*, fractured humerus of Cat 20, *B* stained slide cut from fractured humerus of Cat 20

*EXPERIMENT 20*—Cat 20 was killed thirty-six days after the fracture. The same operation was performed as on Cat 17, the saw breaking, and the division of the bone being completed with Liston bone forceps.

When the cat was killed, the wound was healed and the hair had grown over the site of operation. The bones, with the tissues immediately surrounding them, were removed. They were apparently overlapped about 2 cm., and there was no sign at all of union.

*Examination of Stained Slide*—The two fragments articulated at an angle, or rather the end of one fragment articulated with the side of the other fragment at almost a right angle, about 2 cm. from its extremity. The end of one fragment had been caught obliquely by the microtome knife so that the patency of its marrow canal could not be determined, but the marrow canal of the other was almost completely shut off with new bone trabeculae whose spaces were filled with dense fibrous tissue. Apparently these bone trabeculae were being

formed from fibrous tissue, for within the marrow canal there was no evidence of endochondral bone formation. On the outside of the end of each cortex of this fragment, the stained slide showed, beneath the periosteum, a fairly regular semicircle of new bone, forming from cartilage, as if in the blind effort to accomplish the classical wiped joint usually found in the healing of fractures. But all this new bone was well encapsulated by fibrous tissue, and showed no tendency to spread across to the other fragment, being separated from it by very dense fibrous tissue which contained clefts or rifts. This dense fibrous tissue extended over the entire end of the fragment forming a thick cap for it, and passing down among the trabeculae in the central marrow canal as noted above.

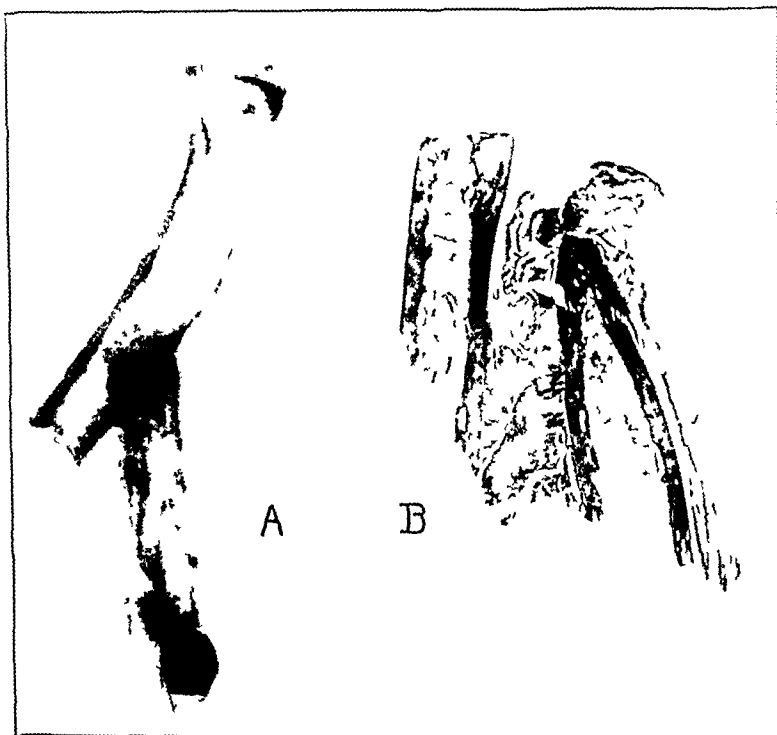


Fig 22—*A*, fractured humerus of Cat 21, *B*, stained slide cut from fractured humerus of Cat 21

The other fragment was capped on the outside of its conical end by new endochondral bone, spongy in its interior but denser at its periphery. This cap of bone was covered almost completely by rather dense fibrous tissue.

*Summary*—There was the formation of a new joint between the end of one fragment and the lateral aspect of the other. Internal and external callus was present.

### THIRD SERIES

In this series a longitudinal incision was made in the periosteum, and the right humerus was divided by Liston bone forceps.

**EXPERIMENT 21**—Cat 21 was killed forty-eight days after the fracture. A lateral incision was made on the fore leg, intermuscular dissection was carried down to the periosteum, and a longitudinal incision was made through the



periosteum The periosteum was separated from the bone, the bone was divided with Liston forceps and was sutured with deep and superficial catgut sutures, and a collodion dressing applied

When the cat was killed the wound was well healed and the hair had grown over it Marked overriding of the fragments was present, but no sign of union

*Examination of Stained Slide*—The marrow canal of one fragment was open, and in the marrow, close to the end, were irregular chips of bone or bone trabeculae, which for the most part appeared to be dead, but the nuclei of some stained well, so that one got the impression that they were partly chips of bone from the fracture being absorbed, and partly new bone building across the marrow canal The ends of the cortex of this fragment were ragged,

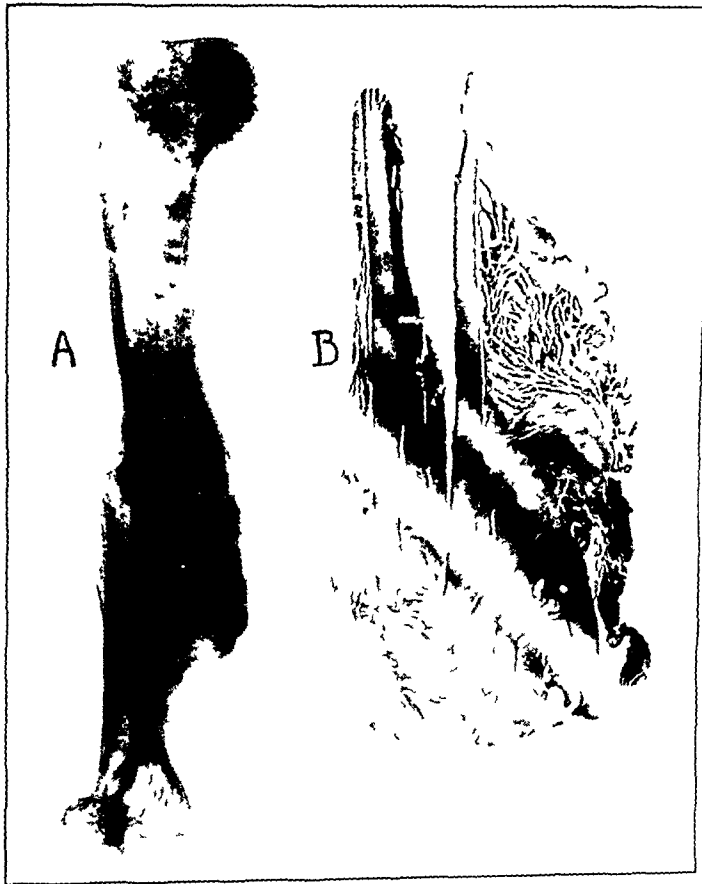


Fig 23—4, fractured humerus of Cat 22, B, stained slide cut from fractured humerus of Cat 22

and the bone of the cortex on the far side from the other fragment stained poorly, while that of the cortex toward the other fragment stained much more distinctly Across the end of this cortex and extending about half way across the end of the marrow canal was dense fibrous tissue, and this fibrous tissue ran across to the other fragment, showing in its structure a marked cartilaginous element as it neared the cortex of the latter In this cartilage, formation of bone trabeculae was beginning, but, whether because of an artefact or not, these trabeculae were not apposed to the cortex A small irregular slit lay between the intracartilaginous bone formation and the cortex

The end of the other fragment had been caught at an angle by the microtome knife, so that the patency of the marrow canal could not be determined. Fibrous tissue extended from near the end of this fragment to the cortex of the other, and this tissue also showed much cartilage in the region of the latter cortex, with new bone trabeculae developing close to the cortical bone. These trabeculae were not separated from the cortex as were the others.

In the connecting tissue were irregular rifts or rents, one of them extending from a spot over the open marrow canal of the one fragment diagonally across, almost to the cortex of the other and in this rent, as in some of the others, were organized masses of fibrin, with the typical shape of synovial villi. Indeed, the sides of the cleft might have been mistaken for synovial membrane.



Fig 24—*A*, fractured humerus of Cat 23, *B*, stained slide cut from fractured humerus of Cat 23

*Summary*—In spite of the small intracartilaginous bone development, there was no indication in this specimen that bony union ever would take place. Everything pointed to the establishment of a new joint.

*EXPERIMENT 22*—Cat 22 was killed sixty-two days after the fracture. The same operation was performed as on Cat 21. The animal was young. When it was killed there was no sign of infection. The wound had healed and the fur had grown over it. Apparently, there was firm union, with a large amount of callus.

*Examination of Stained Slide*—The fragments overlapped and the end of one had been caught by the microtome knife obliquely so that whether or not its marrow canal had been shut off by new bone could not be determined. On

the side of its extreme end, toward the other fragment, was a fairly large mass of newly developing intracartilaginous bone, and some distance from the end, also on this side, toward the other fragment and continuous with the cortical bone, was a narrow strip of new intracartilaginous bone still in the stage of development. Dense fibrous tissue in bundles separated this fragment from the other, and in this fibrous tissue were long and well defined rents. In places along the side of these rents, organizing fibrin could be seen with an appearance typical of synovial villi. Apparently, the formation of a new joint was rather well advanced.

The end of the marrow canal of the other fragment was well walled off with new bone, and the fibrous tissue dividing the two fragments passed over this new bone. Over the end of this fragment in the fibrous tissue, the rents

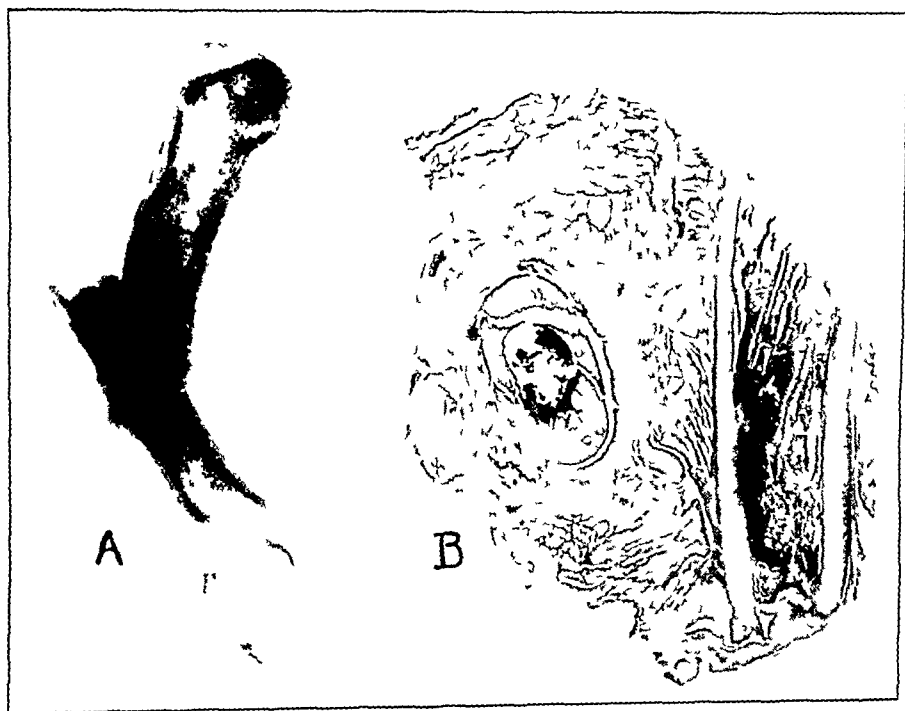


Fig 25—*A*, fractured humerus of Cat 24, *B*, stained slide cut from fractured humerus of Cat 24

were continued with their villous formation. The sides of the cortex of this fragment showed no new bone, but in the fibrous tissue at the extreme end of this fragment, and separated from it by a small interval, was a small mass of new intracartilaginous bone.

*Summary*—There was new joint formation. The bones were united by fibrous tissue containing clefts or rents.

**EXPERIMENT 23**—Cat 23 was killed after forty-one days. It was evidently quite a young cat. The operation was the same as that performed on the two preceding cats. When the animal was killed, there was no sign of infection and the hair had grown over the wound. Apparently, firm union was present, with considerable callus.

*Examination of Stained Slide*—The fragments overlapped about a centimeter, with an interval of about 0.5 cm laterally. The marrow canals of both

bones were almost completely shut off by new bone trabeculae with a rather dense spongy structure. The two fragments were joined by a mass of cartilage and bone which was not homogeneous in structure. Near one fragment it consisted almost exclusively of cartilage and near the other fragment of bone. This mass of cartilage extended over the end of each fragment, and over almost the entire mass, the periosteum could be traced. New bone trabeculae, the so-called internal callus, were seen on the inner aspect of the cortex of one fragment, and in its central canal.

*Summary*—There was cartilaginous callus binding the two bones together laterally. Ossification of this cartilage was well advanced. The ossification was proceeding from the cortices, and apparently in time would be complete.

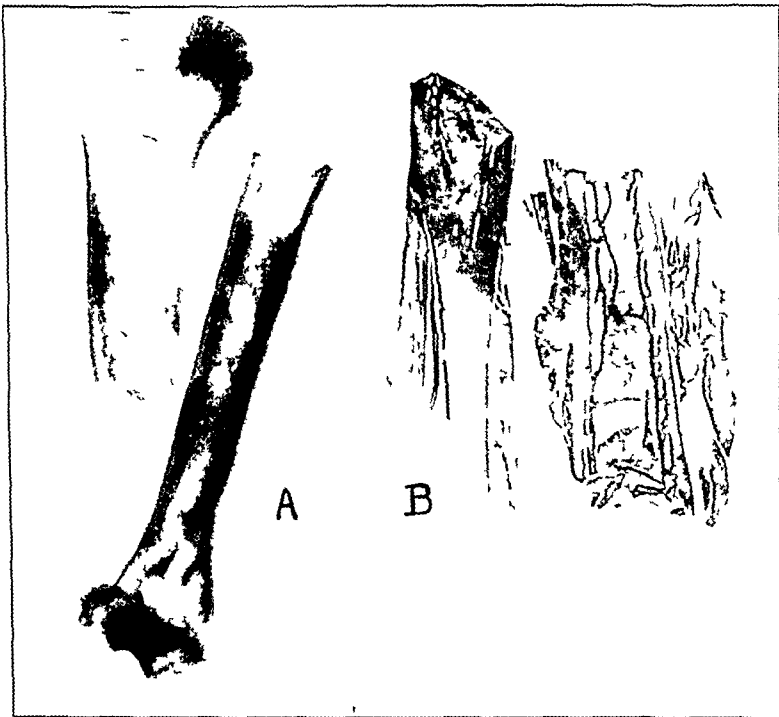


Fig 26—A, fractured humerus of Cat 25, B, stained slide cut from fractured humerus of Cat 25

**EXPERIMENT 24**—Cat 24 was killed after twenty-two days. The same operation was performed as on the three preceding cats. When the cat was killed, the wound in the skin was healed. The fragments had overridden and there was no evidence of union. On cutting down to the fracture a focus of pus was opened, in which the distal end of the proximal fragment lay bare and rough.

*Examination of Stained Slide*—The fragments had been cut at such an angle by the knife that little could be told as to topography. Each fragment showed beginning endochondral bone formation on the outside of its cortex, but no attempt at union of the two fragments was evident. They were separated by an interval of about 0.5 cm, and this interval was occupied by muscle and fibrous tissue in rather loose bundles, with many rifts.

*Summary*—While it was too early to say positively, apparently the bones would not have united in this case. Infection about the end of one fragment

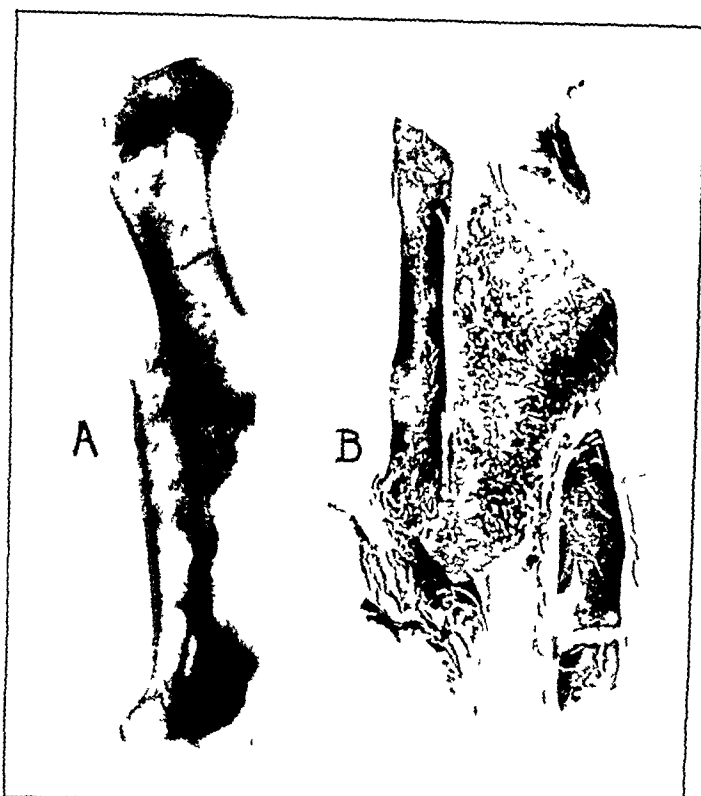


Fig 27—*A*, fractured humerus of Cat 26, *B*, stained slide cut from fractured humerus of Cat 26



Fig 28—Cross section of tibia of cat, showing trabeculae forming in the marrow beneath the hole made in the cortex,  $\times 4$

EXPERIMENT 25—Cat 25 died after four days. The operation was the same as that performed on the last four cats. The periosteum was separated from the bone with difficulty. The cat died of an unknown disease. There was no sign of infection about the wound. Marked ecchymosis was present, and the fragments were loose.

*Examination of Stained Slide*—The end of each marrow canal was shut off by a blood clot, and in one of these clots were a number of small spicules of bone, evidently broken off at the time of fracture. The periosteum was thickened, and in the neighborhood of the fractured end hemorrhage had taken place beneath it.

*Summary*—There was hemorrhage in the marrow, and under the periosteum.

EXPERIMENT 26—Cat 26 was killed after fifty-five days. The same operation was performed as on the preceding five cats. When the cat was killed the wound had healed, and the fur had grown over it. Moderate callus was present, with firm union.

*Examination of Stained Slide*—The fragments had overridden somewhat less than a centimeter, and laterally were about 0.5 cm. apart. The end of one bone had been caught at an angle by the microtome knife, so that the cortex was pointed, and shut off the marrow canal in the slide. Whether or not the canal actually was shut off, it was impossible to tell. The marrow canal of the other fragment was partially shut off by new bone trabeculae. A few scattered trabeculae were also seen in the marrow in the immediate vicinity of this attempt at closing off. The overlapping fragments were tightly welded together by a mass of new bone, which evidently had been developed from cartilage, but there was no new bone on the off side of either fragment, and no evidence of any internal callus—no new bone trabeculae on the inside of the cortex. The new bone callus was continuous directly with the apposed cortices. The periosteum was continuous over much of the new bone, but on account of the stripping of the soft parts from the specimen on the slide, its continuity could not certainly be determined.

*Summary*—There was firm bony union, apparently through the medium of cartilage. The new bone was directly continuous with that of the apposed cortices.

#### COMMENT

These three sets of experiments were undertaken to demonstrate the truth of a theory which I have taught my classes for a number of years, namely, that after a fracture, the periosteum serves as a bridge in which nature builds bone, and that nonunion is usually due to the absence of this bridge<sup>1</sup>. Not only do the experiments fail to demonstrate this, but they show that the theory was false. In none of the slides was there any evidence of any active part taken by the periosteum in the actual formation of new bone, and yet the most cursory inspection of the results demonstrates that the periosteum must play an important rôle of some kind, for where it was divided, there nonunion regularly resulted. The exact rôle of the periosteum in bone formation, and especially in the healing of fractures, has been the subject of much discussion. Indeed, the whole subject of the formation of

<sup>1</sup> Ely, L. W. The Formation of Bone, *Ann. Surg.* 69:225 (March) 1919.

bone is still far from settled. These experiments throw light on both problems, but before considering them, we may profitably spend some time on a general study of bone formation. The study cannot be opened better than by an accurate definition of the terms employed.

Bone is an animal substance composed of organic material consisting of cells and intercellular substance, the latter impregnated with salts of lime and magnesium.

Marrow is the soft tissue within the bone—all the soft tissue within the bone, except the bone cells themselves. Its situation, not its composition, determines its name. Wherever there is bone there is marrow, and no matter what the composition of a tissue may be, if it is not situated within the bone, it is not marrow. Thus, small pockets of tissue with all the characteristics of marrow are occasionally seen in the region of the joints, on the outside of the cortex, immediately under the periosteum, but this is not marrow.

Periosteum is the tissue which covers bone in all situations not covered by the articular cartilage. As with the marrow, the situation of this tissue determines its name, not its structure. It usually consists of fibrous tissue, but in places it may consist of cartilage or of fibrocartilage.

If one looks through a microscope at the periosteum and the cortex of a growing bone, that is, of a bone of a child, one will see, lying on the cortex, numbers of bone cells or of osteoblasts. The trabeculae of the bone within the shaft present the same appearance whether they are being built up or torn down. These cells on the outside of the cortex, in a sense, may be said to be part of the periosteum, but really they have nothing whatever to do with it. They belong to the bone on which they lie. Nevertheless, they are responsible for the widely held opinion that the periosteum has two layers in its structure. Ollier first promulgated this theory, and poetically likened the periosteum to the bark of a tree, with its cambium layer. His theory gained almost universal acceptance until MacEwen challenged it a few years ago.

In the quiescent bone of the adult, nothing like a second layer of the periosteum can be made out. This subject is really not a question for debate. We cannot assume the presence of two layers because our clinical observation teaches us they should be there, and as far as I have been able to find out, no evidence other than clinical ever has been adduced for the presence of two layers of the periosteum in the adult bone.

Fibers of the periosteum run down into the bone cortex, but, as soon as they enter the bone they cease to be part of the periosteum, and become part of the marrow.

Cartilage is a connective tissue consisting of cells and of a homogeneous or fibrillar basement substance impregnated with chondromucin.

Typical cartilage is easily identified, but in certain cases the identification is only possible by recognizing the peculiar cartilage cells in their capsules. When these appear in fibrous tissue, we call the tissue fibrocartilage.

#### THE FORMATION OF BONE

Two theories have been held as to the formation of bone in general. According to the first, the metaplastic, the members of the connective tissue group have the inherent power to change from one to another under certain circumstances, without the influence of any active outside agent. This theory has been almost abandoned, and has been replaced by the osteoblastic theory. According to this theory, bone is formed as the result of the action of a bone forming cell—the osteoblast. We assume that there is such a cell, but we do not know its derivation, and we have no means of identifying it under the microscope. It is supposed to be a small cell, with a deeply staining, round or polyhedral nucleus, frequently seen on the borders of bone trabeculae. When we see such cells on the trabeculae, we are wont to say that they are osteoblasts, and that bone is being built up in this situation. This, however, is not always the case. Similar cells are seen in that situation when we know very well that the bone is being torn down. Moschcowitz<sup>2</sup> says that the osteoblast is simply a differentiated endothelial cell from the wall of the blood vessel. At any rate, unless the osteoblast is the same thing as a cartilage cell, it must be brought to the tissue to be converted into bone, either in the blood stream or in the wall of the blood vessel, for bone formation never begins in cartilage, or, for that matter, in any other tissue, until the blood vessel pushes its way in.

We assume, then, some specific cell, the osteoblast, as the active agent in the formation of bone—the builder, so to speak. The next question is: Out of what is bone built? It may evidently be built out of one of a number of materials. It may be built out of cartilage—intracartilaginous formation. It may be built out of fibrous tissue—intramembranous bone formation. Apparently, bone may also be manufactured out of amorphous or granular necrotic material, as in old inflammatory processes in lymph nodes, or in kidneys whose arteries have been tied off.<sup>3</sup>

The third thing that is necessary for bone formation is a stimulus, pathologic or physiologic, as the case may be. Function is a stimulus, as is the mere presence of bone. If a piece of bone is removed from a live animal, and then if it is immediately buried in the same animal,

<sup>2</sup> Moschcowitz, Eli. The Relation of Osteogenesis to Ossification, *Bull Johns Hopkins Hosp* **27** 71 (March) 1916.

<sup>3</sup> Lick. Zur Frage der heteroplastischen Knochenbildung, *Arch f klin Chir* **80** 279, 1906.



the bone and its contained marrow die.<sup>4</sup> Whatever happens thereafter in that piece of bone and marrow, therefore, must be the result of activity from the surrounding tissues. The first thing that happens is the pushing in of blood vessels from these tissues, and, if the fragment is covered in any part of periosteum, at that part vascularization first takes place.

Following the penetration of the blood vessels, two distinct and opposite processes start in this sterile, dead piece of bone, on the one hand, rebuilding with new, live bone, and on the other hand, clearing away and absorption of the fragment. According to circumstances, one or the other of these processes will prevail, and the fragment will persist and even, in certain circumstances, increase in size, or it will disappear. The mere presence of the dead bone causes new bone to be formed (one stimulus) but if there is no function (a second stimulus) absorption will exceed rebuilding, and the fragment eventually will disappear.

A third stimulus is irritation, as for instance, about an old suppurative osteomyelitis. Normal growth carries with it a fourth stimulus, whose existence we recognize, but whose nature we do not understand. We note that, at a certain period of existence, the blood vessel penetrates the cylinder of cartilage or the epiphysis, and initiates ossification, and that until full growth is attained, nature continues to lay down new bone on the outside of the cortex, and then ceases. Just what starts this physiologic bone growth, and just why it stops, we do not know. We observe it, and let it go at that. But wherever bone is being formed, the blood vessel is the active agent in the process.

We see then that bone may be formed either in the marrow or, perhaps, in the periosteum at the surface, but neither of these two tissues actually forms bone, and bone may be formed without either of them, as in cartilage.

It is well known that the ends of the cortex of a fractured bone possess in themselves little or no power of repair. If a hole is bored in the cortex of a long bone of a laboratory animal, the fractured end of the cortex takes very little part in the subsequent healing. Nature does not simply bridge across the hole in the cortex with new bone as one would think, but she carries out her purpose by means of an internal and an external callus.

The external callus is small in amount, and consists of scattered trabeculae, mostly in the immediate neighborhood of the cortex beneath the periosteum. Where the hole was made in the periosteum, that is,

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<sup>4</sup> Ely, L. W. and Cowan, J. F. A Study of Buried Bone. *J. Orthop. Surg.* 1: 100 (Feb.) 1919, An Experimental Study of Buried Bone. *Ann. Surg.* 70: 747 (Dec.) 1919.

immediately over the hole in the bone, there the formation of bone occurs quite late. The major part of the healing is brought about by the so-called internal callus, that is, by bone trabeculae laid down in fibrous tissue in the marrow, and connecting with the inner aspect of the cortex. This makes a bridge of spongy bone in the marrow across the hole, whose trabeculae connect through the hole, by trabeculae laid down in fibrous tissue and perhaps in cartilage, with the trabeculae in the external callus. The resulting mass of callus of spongy bone has been likened in shape, by E. H. Nichols, to a collar button, with its large flange in the marrow, and its small flange in the periosteum. The connecting shank slowly increases in density until it fills up the hole, but does not establish continuity with the cortical bone at its side until a very late period. In other words, the cortical bone about the hole has played a passive part in the whole process. Everything has been done from the internal and external aspect of the cortex, in the marrow and beneath the periosteum.

We have no means of ascertaining how nearly the foregoing process is imitated in an accurately adjusted fracture of a long bone. The shank of the collar button is probably infinitesimal in thickness, and the roentgen rays indicate that the large flange is not in the marrow but in the periosteum. In fact, the whole essential part of the union seems to take place in, or under, the periosteum and this roentgenographic phenomenon has gone far to strengthen the theory of the "bone forming" function of the periosteum.

That the periosteum plays an important rôle in the healing of fractures is evidenced by other facts, notably by the fact that nonunion is notoriously frequent in those bones or portions of bone not covered by periosteum. e. g., the neck of the femur, the head of the radius, and perhaps the carpal navicular in the region where it is usually fractured. On the other hand, we know that even in these fractures, if we can hold the fractured surfaces firmly together in complete immobility, union may be expected. This union could take place in only two ways, namely, by direct union between the fractured surfaces or by the formation of an internal callus. Apparently, an external callus does not form in the absence of the periosteum. In other words, in the absence of the periosteum, firm apposition and absolute immobility are necessary for union, in the presence of periosteum, they are not.

Nature has the greatest difficulty in bridging the smallest space with bone, and clinically it appears that some function of the periosteum is concerned in throwing the first bridge across. Just what this function is, has been the subject of much dispute.

There is a widely accepted theory that two raw bony surfaces brought together will unite. As has been said, they will not unite

unless held firmly together in immobility. This is true not only of fractures but also of resections. After resections also, two processes are set in motion, one of joint building, and the other of ankylosis. In the human subject, the knee is about the only large joint in which bony ankylosis regularly can be obtained. In the others, fibrous ankylosis usually follows a resection. In the knee two extensive bony surfaces can be brought into close apposition, and can be held firmly together. In other joints, these indications cannot be fulfilled. The elements of extensive apposition and immobility must be the determining factors in the human knee, for after resection of the dog's knee, bony ankylosis is very hard to secure. A new joint usually results.<sup>5</sup>

The first thing that attracts our attention in a consideration of the results of the experiments is the difference in the proportion of bony union to false joint in three series. In the first series, that with simple fracture, bony union regularly resulted if the cat was permitted to live for five weeks. In the second series, in which the periosteum was divided circularly, nonunion was the rule. Bony union took place in only one cat of this series. In the third series, that in which the periosteum was slit, bony union was about as frequent as new joint formation. From these facts the first conclusion to be drawn is

1 *The periosteum has a function to perform in the healing of fractures.* The periosteum is not indispensable, for union may take place when it is slit or divided.

The next thing that interests us is the exact method of union. The specimens throw much light on this. In the first place, we note an entire absence of any bone-forming action in the periosteum. It is not even serving as a bridge or scaffold for the formation of bone, a function which I have persistently assigned to it. Its whole function seems to be to protect, to contain the soft callus between the fragments, to hold it against the fragments, so to speak. The specimens show that MacEwen was essentially right in regarding the periosteum as a *limiting* membrane. I have hitherto denied this. I was wrong.

As to the so-called internal callus, my specimens show no evidence of any effective rôle played by it in the process of union. Sometimes scattered trabeculae appeared within the marrow canal, and sometimes there was no bone formation there at all, but even when present, the trabeculae were apparently not serving any useful purpose. It seems, then, that while this internal callus is the chief means whereby nature repairs the damage done by boring a hole in the cortex, when there is

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<sup>5</sup> Ely, L. W. Experimental Resection of the Dog's Knee Joint, *Ann Surg* 70:586 (Nov.) 1919. Ely, L. W., and Cowan, J. F. Experimental Resection of the Dog's Knee Joint. *Bone and Joint Studies*, I, Stanford University. Published by Stanford University 1916.

an actual solution of continuity between the fragments of a fracture, the internal callus is a negligible factor. This is in line with the impression which one gets from studying roentgenograms of fractures clinically. These show that the whole process of repair takes place outside the cortex.

In almost all our specimens, marked displacement of the fragments had taken place, and they were separated by a distinct interval. This interval, bounded on two sides by cortex, and on two sides by periosteum, became filled with cartilage, fibrous tissue and fibrocartilage. Union of the two fragments took place by ossification of this mass of cartilage and fibrocartilage very much as ossification takes place in an epiphysis, by the penetration of blood vessels. The ossification advances from the cortex, and is especially marked in the angle made where the periosteum leaves the cortex. In no case was there any evidence of bone formation along the periosteum where it stretched across between the fragments. In other words

2 *Ossification of the soft callus takes place from the external aspect of the cortex.* This also agrees with roentgen-ray evidence. What has been assumed from roentgen-ray evidence, however, to be a bony bridge built by the activity of the periosteum, is really the result of bone formation proceeding from the cortex. The few experiments which were allowed to run for a considerable time indicated that after bony union was complete, the apposed and overlapping cortices were being torn down, and that a rearrangement of the bone architecture was going forward. Presumably, a new cortex would be formed in the bony callus, and a central medullary canal would be established within it.

In the cases of nonunion, the fundamentals of the formation of the soft callus were the same as in the other cases, except that the production of fibrous tissue was possibly more abundant. New bone developing from cartilage appeared on the outside of the cortex in these cases also. The chief distinguishing mark in these two series was the formation of rifts in the fibrous tissue of the soft callus, and when the soft callus was transformed partially or completely into cartilage and bone, the large rift or series of rifts constituted a regular joint, lined by cartilage or by fibrocartilage, sometimes in places showing a distinct villous formation, like that of a synovial membrane.

This formation of a new joint is the rule in the series of experiments in which circular division of the periosteum was carried out. Only one case of the series showed bony union. The series in which the periosteum was slit does not show this almost uniform tendency. The cases are too few for accurate judgment, but, roughly, bony union is about as frequent in the uninfected cases which have run a sufficient time as is new joint formation. In other words

- 1 When the periosteum is intact, bony union is to be expected
- 2 When the periosteum is completely divided, bony union is not to be expected
- 3 When the periosteum is slit, bony union may or may not take place

#### CONCLUSION

After an ordinary fracture, hemorrhage takes place from the marrow canal under the periosteum. The periosteum is stripped up from the cortex by this hemorrhage and by the fracture itself. Then come the deposition of fibrin, the formation of granulation tissue and the formation of cartilage and fibrocartilage in the space beneath the stripped-up periosteum. Probably the function of the periosteum is only important in the early stages, up to the formation of the cartilaginous callus. The periosteum probably serves to keep the hemorrhage from escaping and the granulation tissue undisturbed. It has no bone-forming function, and bone is not built out of it. The subsequent ossification of the cartilaginous callus is carried out almost entirely if not exclusively, from the external aspect of the cortex. The internal callus plays no effective part in the union. It is rudimentary when it is present.

# FRACTURE OF THE TIBIAL SPINE

## AN EXPERIMENTAL STUDY<sup>†</sup>

FRANK E. BLAISDELL, SR., M.D.

SAN FRANCISCO

The present article is the result of experimental observations on fracture of the tibial spine. The work was done on cadavers. It consisted mainly of demonstrations before classes of students, during the regular courses on fractures and dislocations, and of experiments made at other times. Textbooks are particularly silent on fractures of the tibial spine when they are not a complication of a more serious injury to the knee.

This form of fracture occurs most frequently as a complication of dislocation of the knee or of fracture of the tibial tuberosities. As a simple uncomplicated fracture it is apparently not so rare as one might be led to believe from textbooks and treatises on fractures in general. In such injuries to the knee as the so-called sprains or twists, it passed unrecognized before the introduction of the roentgen rays.

It is not my object at present to consider fracture of the tibial spine as a complication, but to consider it as an uncomplicated fracture with a minimum amount of damage to some of the ligaments of the knee joint.

### ANATOMY

It is essential to consider briefly the salient anatomic characteristics of the ligaments of the knee joint in order to follow closely what will be said regarding the experiments and mechanisms involved and also to be able clearly to account for the pathologic condition.

The knee joint is the largest and one of the most superficial joints of the body. It owes its remarkable strength not only to its bony construction but also to the strong resisting ligaments, reenforced by one of the strongest fascias of the body—the fascia lata, together with the tendon of the powerful quadriceps extensor muscle, which binds and holds the parts together. The expansion and mutual blending of these fibrous structures, along with the other ligaments to be mentioned, add stability to the osseous constitution of the articulation, and enable it to withstand the leverage of the two longest bones of the body. The great size of the bone ends is important in determining more advantageous leverage by which the strain on the ligaments is lessened.

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It may be well to remember that the knee joint in some of the lower animals is composed of two separate joints, one for each condyle, and the crucial ligaments of man are the representatives of lateral ligaments when these joints exist as separate entities

*Crucial Ligaments* (Fig 1) —These ligaments of the knee are interosseous, being situated within the joint but external to the synovial membrane. They are named anterior (lateral) and posterior (medial) from the position of their attachment to the tibia. Gray says that they possess considerable strength, while Treves<sup>1</sup> refers to them as being very powerful.

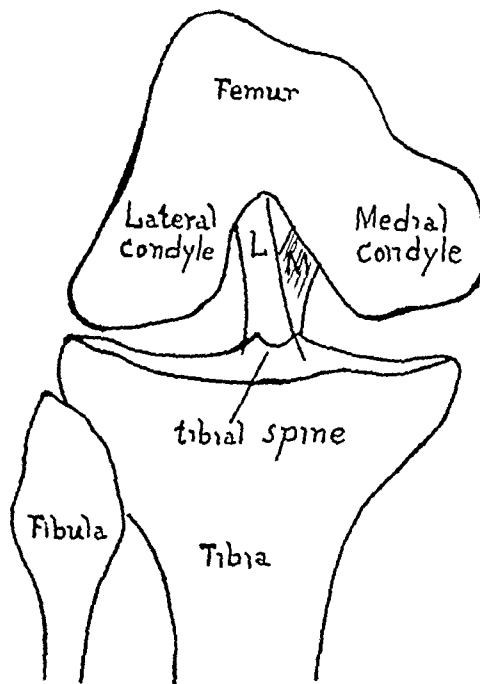


Fig 1—Outline drawing showing the crucial ligament of the knee joint L, anterior crucial ligament, M, posterior crucial ligament

The anterior crucial ligament is attached to the depression in front of the spine of the tibia, being blended with the anterior extremity of the lateral meniscus, and passing obliquely upward, backward and outward, it is inserted into the inner and back part of the lateral condyle of the femur.

The posterior crucial ligament is stronger, shorter and less oblique in its direction than the lateral. It is attached to the back of the depression behind the spine of the tibia, to the popliteal notch and to the posterior extremity of the lateral meniscus, passing upward, forward and inward, to be inserted into the outer and forepart of the inner condyle of the femur, where it blends with the ligamentum posticum.

<sup>1</sup> Treves, Frederick. *Surgical Applied Anatomy*, Ed 7, revised by Arthur Keith and W. Colin Mackenzie, 1917.

*Collateral Ligaments*—There are two of these, the lateral and medial Treves considers them comparatively feeble The lateral ligament consists of two parts, the fibular collateral and a short, or posterior, portion

The fibular collateral is a strong, rounded fibrous cord, attached above to the back of the lateral tuberosity of the femur, below, to the lateral part of the head of the fibula Externally, it is covered by the tendon of the biceps muscles, which divides at its insertion into two parts, separated by the ligament The tendon of the popliteus muscle and inferior external articular vessels and nerves passes beneath it Piersol considers this ligament as truly distinct

The short, or posterior, part may be absent It is an accessory bundle behind and parallel to the preceding It is attached above to

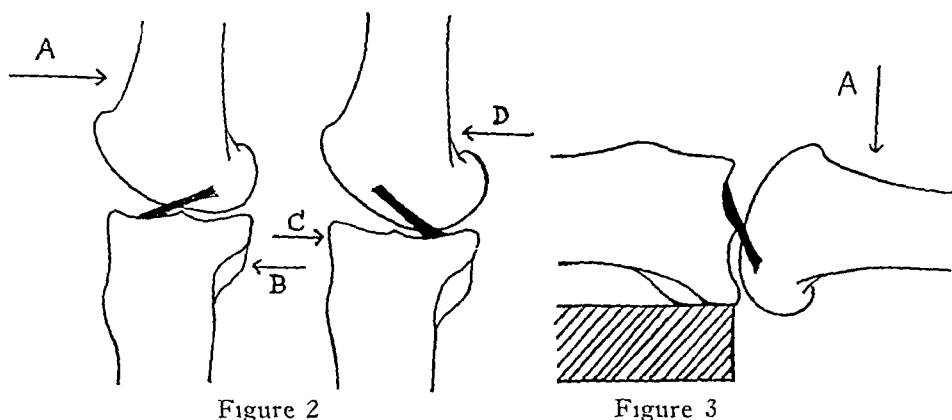


Figure 2

Figure 3

Fig 2—Outline drawing showing where force was applied to throw tensile stress upon the anterior crucial ligament (left), and upon the posterior crucial ligament (right)

Fig 3—Outline drawing showing how the leg was supported and where force was applied to produce fracture of the tibial spine as shown in Figure 4

the lower and back part of the lateral tuberosity of the femur, below, to the styloid process of the fibula and is inseparable from the capsule Passing beneath it are the tendon of the popliteus muscle and the inferior lateral articular vessels and nerves

The medial, or tibial collateral, ligament is a well defined, strong, flat fibrous band, thicker behind than in front It is attached above to the medial condyle of the femur, below, to the medial tuberosity and medial surface of the shaft of the tibia to the extent of about 2 inches (5 cm) It is crossed, at its lower part, by the tendons of the sartorius, gracilis and semimembranosus muscles, a synovial bursa being interposed Its deep surface covers the anterior portion of the tendon of the semimembranosus with which it is connected by a few fibers the synovial membrane of the joint and the inferior articular



vessels and nerve. It is adherent to the medial meniscus. Piersol considers this ligament as only a part of the capsule artificially separated. Both collateral ligaments are situated nearer the back than the front of the joint.

*Ligamentum Patellae*—This ligament is that part of the quadriceps extensor tendon in which the patella is a sesamoid bone. It is a strong flattened fibrous band, about 2 inches (5 cm) long, and inserted into the tibial tubercle. It is fused at the sides with fibrous expansions from the quadriceps extensor muscle.

*Capsula Articularis*—This forms the ligamentum posticum which is strengthened above by oblique fibers from the tendon of the semimembranosus muscle, forming Winslow's ligament. The capsule as a whole is very thin but strong fibrous membrane filling in the intervals between the stronger parts named above, which in part are inseparable from it.

#### SURGICAL ANATOMY

Almost all of the facts presented here have been reviewed on the anatomic preparations in the teaching collection of the laboratory of surgical pathology of the Medical Department of Stanford University. It is very important that they be repeated although more or less extant in textbooks and in the literature.

Regarding the crucial ligaments, Treves states that they are more or less tense in all extreme positions of the joint. The anterior ligament especially resists extension, forward displacement of the tibia and rotation inward of the leg, while the posterior resists extreme flexion and displacement backward of the tibia. In the moment of extension, the tibia slides slightly forward and is rotated slightly outward. In flexion it glides backward and rolls slightly inward. The center of rotation of the tibia, when near the position of extreme extension, passes behind the lines joining the points of insertion of the collateral ligaments, so that the knee automatically locks in the position of extreme extension. In this position the locking arrangement permits stability with a minimum of muscular action in standing. Therefore, the standing position is less fatiguing than it otherwise would be.

On the whole, extension generally is limited by the crucial ligaments, flexion by the ligamentum patellae and anterior part of the capsule in addition to the crucial ligaments.

We should be familiar with the fact that rotation of the knee is possible only in the flexed position. The patellar ligament is tense in flexion, and relaxed in extension when the quadriceps extensor muscle is relaxed. Acting in conjunction with the anterior portion of the capsule, it limits excessive flexion, especially in the emaciated, less so in the adipose, as the soft parts are more prominent and naturally

diminish the range of flexion Both collateral ligaments are tense during extension and relaxed during flexion Together they withstand the lateral strains and also check hyperextension and outward rotation The ligamentum posticum limits extension

Lange believes that the crucial ligaments together limit or prevent forward and backward sliding, and that both are more or less tense in all positions of the knee joint, with the exception of flexion Here he disagrees with Treves Davis states that these ligaments are not tense in all positions, for in flexion they become slightly relaxed Robert Jones<sup>2</sup> states that both crucials check inward rotation of the tibia

It must be borne in mind that no two joints are exactly alike as regards the relative length, strength or size of the parts This natural variation no doubt accounts for slight differences of opinion among authors

#### EXPERIMENTS

Having considered the normal functions of the ligaments of the knee joint, it is logical to inquire what happens when excessive stress is thrown upon the joint in various directions The following questions set forth the problems involved

1 What occurs when force is applied to the lower and anterior part of the thigh just above the condyles of the femur, in a backward and slightly outward direction, with the leg in extension and fixed?

2 What occurs when force is applied to the upper and back part of the leg, when it is extended and the thigh is fixed?

3 Can fracture of the tibial spine, rupture of a crucial ligament, or avulsion of a fragment of bone from the femoral condyles be produced without visible or, at most, but slight injury to the collateral ligaments, rupture of fascia, fracture of the femoral condyles or tibial tuberosities other than those produced by direct pull on the crucial ligaments?

4 What happens when forcible stress is exerted laterally against the knee when in a state of extension? When in a state of flexion? Which gives way first, the collateral or the crucial ligaments?

5 What happens when forcible stress is exerted in a rotatory direction, either when the leg is in extension or flexion, outward rotation being normally limited by the collateral ligaments, and inward rotation normally limited by the anterior crucial ligament?

In the living subject as well as in the cadaver, stress will unavoidably be exerted in several directions simultaneously, the results being influenced by position and the individual anatomic peculiarities in each case

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<sup>2</sup> Jones, Robert Sect VIII, *Injuries to Joints*, Oxford Loose-Leaf Surgery, New York, Oxford University Press 1 812, 1918

*Technic*—The part to which the force is to be applied is covered by a thick pad, formed usually from an ordinary sheet which is folded a number of times until it is about 12 inches (30 cm) square. The blow is struck with a club made from a scantling 4 inches (10 cm) wide, thus giving a broad surface. The joint after production of the injury is opened by making a large oval patellar flap which is reflected downward, giving a good exposure of the interior of the knee.

#### REPORT OF EXPERIMENTS

*Experiment 1*—This was performed on the cadaver of a young, husky colored man, whose limbs were rigid. The body was placed in a prone position. The distal extremity of the right thigh (femur) was supported on a 4-inch (10 cm) block placed beneath the femoral condyles. The distal part of the leg was supported in a similar way. The thick pad was thrown over the upper part of the sural region, and a heavy blow was delivered in such a way as to drive the tibia forward and a little inward on the femur (Fig 2 B), the object being to produce tensile stress in the direction of the longitudinal axis of the anterior crucial ligament.

*Result*—This was doubtful on account of the great muscular rigidity. The knee joint was opened as described above. An examination of the interior of the joint demonstrated the parts intact. The blow was repeated with the joint open.

*Examination*—Fracture of the tibial spine occurred close to the insertion of the anterior crucial ligament.

*EXPERIMENT 2*—The same technic and mechanism were employed on the left knee.

*Result*—Rupture of the anterior crucial ligament occurred.

*EXPERIMENT 3*—This was performed on the cadaver of a middle aged white man, whose extremities were rigid, with possible flexion of not more than 10 degrees. The body was placed in a supine position. The tibia of the left knee was supported on a block, the end of which was flush with the articular surface of the tibia (Fig 3). A pad was applied over the distal and anterior surface of the thigh and a heavy blow was delivered just above the condyles (Fig 3 A) in such a way as to drive the femur backward and a little outward, the object being to produce tensile stress on the anterior crucial ligament, in the direction of its longitudinal axis.

*Result*—Laceration of the anterior crucial ligament occurred.

*EXPERIMENT 4*—The same technic and mechanism were employed on the right knee as in Experiment 3.

*Result*—Laceration of the anterior crucial ligament resulted.

*EXPERIMENT 5*—This was performed on the cadaver of a white man, aged 91 years, a laborer. The body was placed in a supine position. The left knee was rigid, very slight flexion being possible. The proximal extremity of the leg (tibia) was supported as in Experiment 3. A pad was thrown over the distal extremity of the thigh and a heavy blow was delivered just above the condyles of the femur, the object being to produce tensile stress on the anterior crucial ligament, as in Experiment 3.

*Result*—A comminuted fracture of the distal third of the femur occurred, with an intercondylar line of fracture entering the joint, also fracture of the tibial spine—a small fragment of bone being torn off by avulsion through pull on the anterior crucial ligament.

EXPERIMENT 6—The same technic and mechanism as in Experiment 5 were employed on the rigid right knee

*Result*—Fracture of the femur occurred at the lower third, as well as fracture of the tibial spine, consisting of a large fragment, measuring 1 by 1.5 cm

EXPERIMENT 7—This was performed on the cadaver of a white man, aged 82 years, whose knees were flexible. The body was placed in a prone position. The distal extremity of the left thigh (femur) was supported on a block which was placed just above the condyles. The distal extremity of the leg was supported by a block, the upper part of the sural region was covered by the usual pad and a heavy blow was delivered just below the tibial tuberosities (Fig 2 B), driving the tibia forward and a little inward on the femur. The object was to produce tensile stress in the direction of the longitudinal axis of the anterior crucial ligament

*Result*—The plica synovialis patellaris was torn over the anterior crucial ligament, a small thin scale of compact bone was torn from the lateral and anterior surfaces of the medial condyle at the point of attachment of the posterior crucial ligament, the anterior ligament being stretched, rupturing some fibers (sprain)

EXPERIMENT 8—The same technic and mechanism were employed on the right knee as in Experiment 7

*Result*—Fracture of the tibial spine occurred posteriorly, the fragment being about 4 mm in diameter

*Comment*—Four cadavers were used for the eight experiments, with the following results

- (a) Fracture of the tibial spine occurred four times
- (b) Laceration of the crucial ligaments occurred three times
- (c) A fragment of bone was torn by avulsion from the femoral condyle once

The fracturing of the femoral shaft in Experiments 5 and 6 was something unusual in the course of such demonstrations. The age of the subject has to be taken into account, for probably senile atrophy of the bone was present. In none of the other experiments was there macroscopic evidence of gross injury

No experiments are given in which the femur was driven forward and slightly inward (Fig 2 D), or the leg driven backward and slightly outward (Fig 2 C), so as to produce tensile stress on the posterior crucial ligament in the direction of its longitudinal axis. The results of such experiments have been just as positive as those reported above, in which stress was thrown on the anterior crucial ligament. As in the case of the latter, one of three things occurs, namely fracture of the tibial spine posteriorly, rupture of the ligament itself, or avulsion of a fragment of compact bone at the point of insertion of the ligament into the anterior and lateral surface of the medial condyle. Macroscopic or objective evidence of injury is just as unusual as in the experiments in which stress was thrown upon the anterior crucial ligament

The results in Experiments 7 and 8 are not in accord with the usual results when stress is exerted upon the anterior crucial ligament. Here an element of variation appears. The anterior ligament was longer than usual or stretched, throwing the tension upon the posterior ligament. Dr Oscar Allis once remarked to me regarding the constancy of results, "If we do not get the results we desire, we get something just as interesting and instructive."

Likewise, there is no report of results of experiments in which force was exerted laterally over the distal extremity of the femur or proximal part of the tibia. In such experiments the collateral as well as the crucial ligaments are involved. The results are fracture of the femoral condyles, or in lieu of this the tibial tuberosity or, laterally, the fibular head, rupture of the ligaments, rarely, fracture of the tibial spine or rupture of the crucial ligaments, or avulsion of a fragment of bone from the femoral condyles through tensile stress upon these ligaments, with a varying degree of dislocation depending on the direction and amount of violence. The giving way of the collateral or crucial ligaments is considered by Ross as an essential of dislocation.

The results of experiments in which rotatory and forcible stress was exerted through the leg, with the thigh fixed, or vice versa, are not so satisfactory on account of the rigidity which is usually present. It is believed that muscular action plays an important rôle in life. Fracture and rupture of ligaments are obtained, but of such a varying kind as to preclude positive predictions.

Dr Ross<sup>3</sup> in his Experiment 48, by fixing the left femur and jerking the leg upward, produced a subluxation of the leg posteriorly on the femur. This leg was dissected with the following results: "Posterior subluxation was demonstrated, with sprain fracture of the inner and outer condyle through the agency of the posterior and anterior crucial ligaments, respectively, sprain fracture of the inner condyle through the agency of the tibial collateral ligament, sprain fracture of the posterior tibia between the tubercles through the agency of the posterior capsule, proved by microscopical section, separation of the fibers of the semimembranosus at the seat of its expansion into the posterior capsule and separation of some of the fibers of the inner head of the gastrocnemius. The two last named fiber separations were clearly visible to the unaided eye." This citation is enough to show the character and degree of injury in such cases.

In the cadaver, muscular influence as a vital factor is necessarily nil. Here the muscles act as splints and more or less neutralize the applied force, depending, of course, on the degree of rigor mortis, or

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<sup>3</sup> Ross, G. G. A Study of Sprain-Fractures as an Essential to the Occurrence of Dislocation, *Ann Surg* 56: 599, 1912.

in the embalmed cadaver on the rigidity due to the embalming fluids, as in my Experiment 1 in which it was necessary to repeat the application of force

#### CITATION OF PUBLISHED CASES

It will be elucidating and convincing to note carefully the similarity in some ways between my experimental cases and certain points in those that follow

Dr Sidney Lange <sup>4</sup> cites two cases of avulsion of the tibial spine

CASE 3—Mr McD, while wrestling, accidentally twisted his left knee and fell to the floor. He suffered great pain but was able to walk to the hospital. Examination was negative, but a roentgenogram revealed a tearing off of the tibial spine

CASE 4—Mr J D, while attempting to alight from a moving street car, twisted his left knee and was thrown violently to the ground. He was unable to arise, owing to great pain in his knee. Examination was negative. A roentgenogram showed a tearing off of the medial condyle of the femur and an avulsion of the tibial spine

These cases show sudden and severe strain on the knee joint, which gave negative evidence of bruising or any signs of fracture

Callender <sup>5</sup> has reported the case of a boy (Case 17), aged 12, of healthy appearance, who gave a history of having "some days previously fallen upon some ice, and had struck his right knee a severe blow over the internal condyle, twisting his leg in his fall. He limped home but his complaints were made light of by his parents. Trouble followed. The knee joint was opened, the wound was allowed to close, pain followed, health failed, pus formed in the joint and the leg was amputated"

Results of examination of the museum specimen were reported thus

"Joint gave the ordinary appearance of an inflamed condition. The lower extremity of the femur, from the lateral condyle of which a slice has been removed, shows on the portion separated, close to the front of attachment of the anterior crucial ligament, a deep cavity lined by a smooth membrane. By its side is suspended a small, oval-shaped portion of bone, which, with its surface bare and rough, was loosely contained in it." The following comment is made: "There can be no doubt that this portion of bone had been unfastened from the condyle by some strain on the anterior crucial ligament and had necrosed, probably from neglect to which the boy was at first subjected"

The following very interesting and convincing case has been reported by Dr Ross <sup>6</sup>

<sup>4</sup> Lange, Sidney. *Ann Surg* 48 117, 1908

<sup>5</sup> Callender, G W. *Fracture Into Joints*, Rep St Bartholomew's Hospital 6 51, 1870

<sup>6</sup> Ross, G G. *A Case of Fracture of Intercondylar Spine of Tibia*, Naval Med Bull 13 294, 1919

E W H, aged 30, ensign, U S S *Douglass*, was admitted March 25, complaining of a swollen and painful left knee. He gave a history of having been struck on the posterior surface of the left leg, just below the knee joint, by a snatch block weighing about 45 pounds (167 kg). His boat was in the harbor preparing to put to sea and the block, being used to hoist the anchor, was under heavy tension and flew about 10 feet (3 meters). After striking the patient, who was thrown 8 feet (25 meters) in the air, the block glanced off and struck a large galvanized iron bucket filled with sand. The impact was so great that it flattened the bucket. The patient was wearing a pair of high hip boots folded down in such a manner that the part of the leg struck was covered by about four thicknesses of rubber.

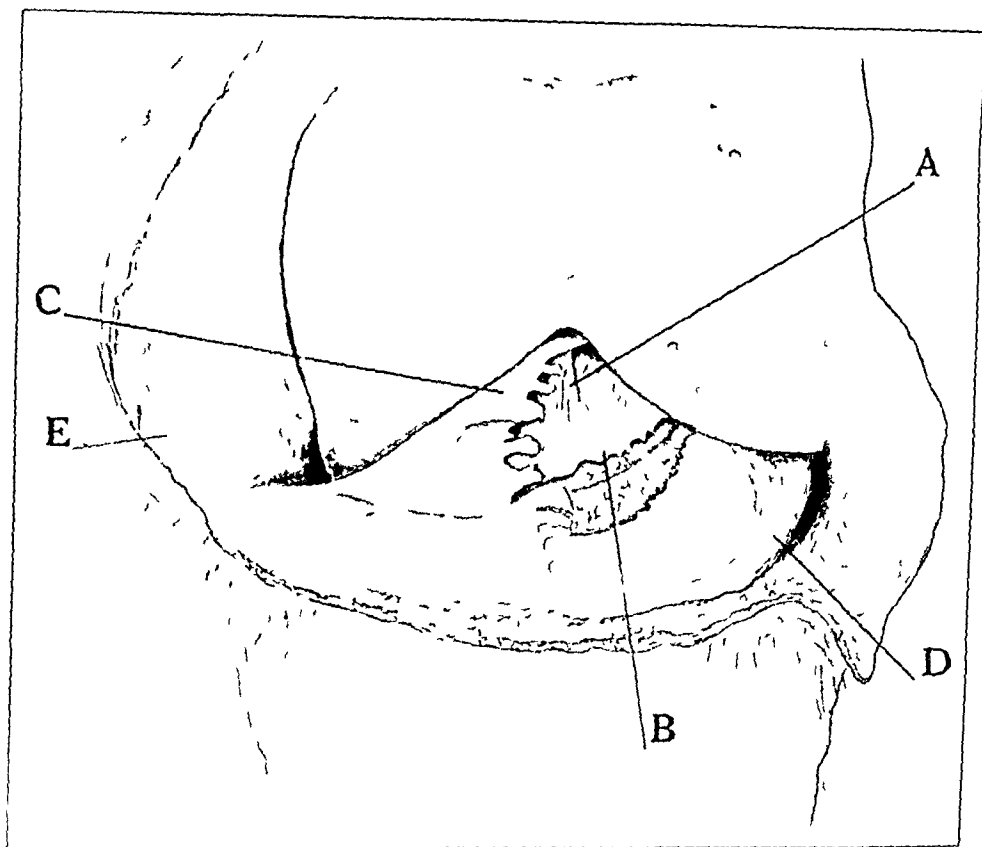


Fig 4—Experimental fracture of tibial spine as a result of tensile stress having been thrown upon the anterior crucial ligament using mechanism shown in Figure 3. (A) ligamentum cruciatum anterius, (B) detached tibial spine, (C) plica synovialis patellaris drawn to one side, (D) meniscus medialis, (E) reflected patella and ligamentum patellae, knee very strongly flexed.

For the moment, the patient was unconscious. The symptoms and treatment are not germane to the subject under consideration and will be omitted.

Roentgen-ray examination revealed a transverse fracture of the intercondylar spine of the left tibia in good position and with some excess callus.

The roentgenograms showed about the same condition as my own experimental case, of which I submit a drawing and roentgenogram (Figs 4 and 5).

## COMMENT

It is important to bear in mind the possibility of variation in the structure of the knee joint, for it may be the clue to differences between cases of injury when the mechanism is similar, and to explain discrepancies in reported clinical cases

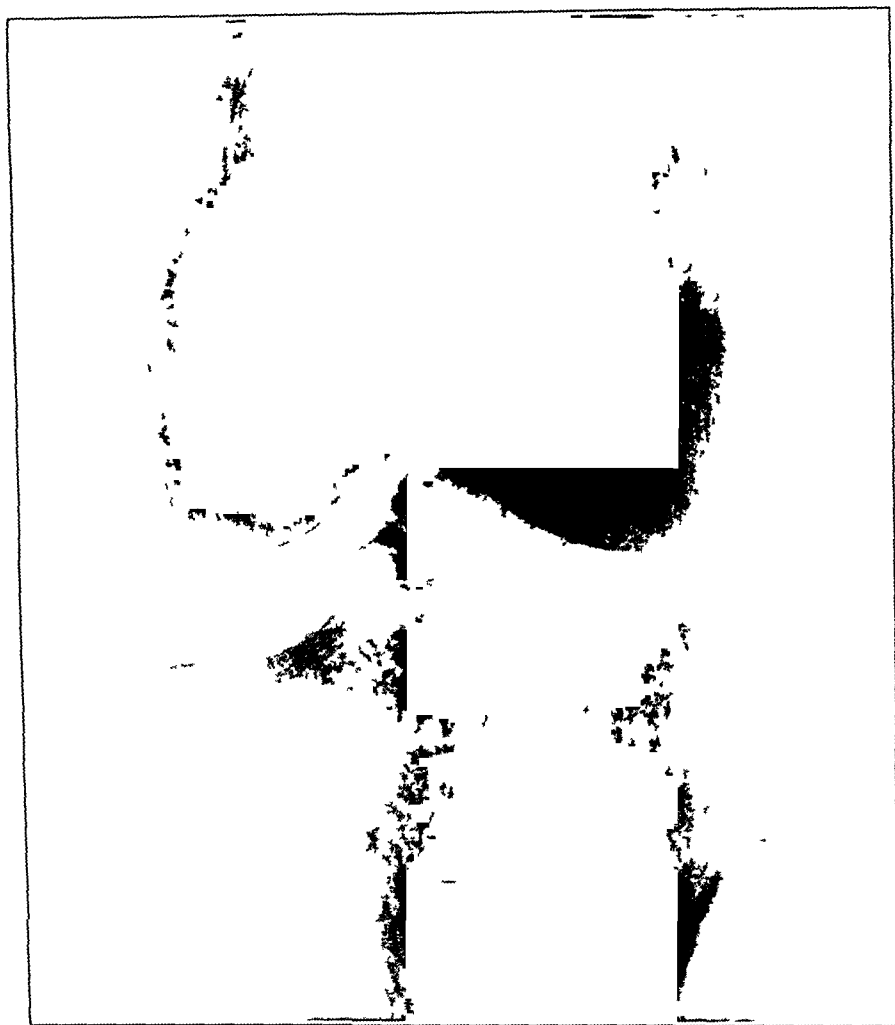


Fig 5—Roentgenogram showing an experimental fracture of the tibial spine, knee in extension, same as Figure 4, mechanism of production same as that shown in Figure 3, right knee, reversed in printing

When stress on a joint is at variance with the optimum physiologic activity, injury is imminent, and the degree of such injury depends upon the relative mechanical advantage or disadvantage, plus the individual peculiarities regarding the relative strength of the several parts at the critical moment. The combination of factors attending each injury is, in all probability, never twice exactly alike.



The condition of loose-jointedness, in different degrees, may affect all or only a part of the ligaments of a joint. In the case of the knee joint the collateral ligaments being of normal or average length impart to the joint a firmness which we recognize as an optimum stability. Any deviation from this condition renders the joint liable to displacements when stress is exerted upon the crucial ligaments, unless the muscles acting on the joint respond in such a way as to supply the firmness that is lacking through looseness of the collateral ligaments. Again, the collateral ligaments may be of normal or optimum length or strength and the crucial ligaments, one or both, unusually relaxed rendering the joint vulnerable to minor degrees of violence, as stress falls upon the collateral ligaments and indirectly upon the muscles that act on the joint.

These variant factors render the joint open to injury from less forcible stresses, and as the whole mechanism at the time of accident is a variable and complex quantity, depending upon the individual peculiarities and combinations of spasmodic muscular activity, it becomes an almost impossible task to determine the details of the mechanism in any case of injury. We must depend on an explanation as best we can.

Treves<sup>1</sup> states that from one surgical point of view, joints may be divided into three groups (1) those that depend for their strength mainly upon ligaments, (2) those that are mechanically strong, and that derive their stability to a great extent from the arrangement of their component bones, (3) those that rely for their support principally upon muscles. The knee joint derives no strength from the shape of the articular surfaces, since they are merely placed in contact with one another, but from its ligaments and secondarily from muscles. In front is the powerful quadriceps extensor muscle of the thigh, the tendon of which acts as a ligament (*ligamentum patellae*) of the joint, posteriorly, the popliteus and relatively strong gastrocnemius of the sural group, medially, the semitendinosus, semimembranosus, gracilis and sartorius, laterally, the biceps.

In the ordinary activities of the joint, the ligaments are reenforced by these muscles, which are in a state of tonic contraction when the joint is functioning. Any deviation from an optimum combination necessary to the normal fulfilment of the physiologic requirements will render the joint vulnerable when stress falls in some particular way.

When sudden stress is thrown upon the joint as at the time of accident, whether it be a misstep, a slip, direct violence or the giving way of the surface upon which the person is walking, a sudden demand for quick and coordinate muscular action is necessitated to reenforce

the joint, if this is irregular and spasmodic and outside the usual action some one muscle acting in a relatively stronger way than normally, injury may follow

Callender<sup>5</sup> says it is the "rule that bone gives way before fibrous tissue" It is evident that in the extended condition of the knee joint twists are without power (unless very violent) to cause injury The condition is quite different when the joint is more or less flexed, as reported cases show The biceps muscle by its power of external rotation plays an important part in the mechanism of resulting injury, or it may be the popliteus, semitendinosus semimembranosus, gracilis and sartorius by their power of internal rotation

Lange<sup>4</sup> calls attention to the relation between the crucial ligaments and the menisci (anterior crucial and medial meniscus, posterior crucial with the lateral meniscus), indicating that strains upon the crucial ligaments will be felt by the menisci and that dislocations of the menisci may be accompanied by sprain-fractures

The facts, then, which must be taken into consideration when studying the results of injury to the knee joint are these Allowances must be made for the different factors entering into the possible mechanism The degree of force is at times not of sufficient moment to do much damage and yet internal injury may be present in the form of a mild strain or stretching of the soft parts, of sprain or sprain-fracture Ross and Stewart<sup>7</sup> define the latter as "a condition resulting from an increase in tension on tendon or ligament, or from direct violence at the seat of tendinous or ligamentous attachment to bone It is a separation of all or a part of that bone to which tendon or ligament is attached, from that bone of which it formed a part"

An analysis, then, of the foregoing, correlated with the results of the experiments already given with those of the clinical cases cited from the literature, permits of the following conclusions

- 1 A strain is a stretching of the soft parts with a minimum amount of damage It is not recognizable macroscopically, causing subjective symptoms

- 2 A sprain is a rupture of the soft parts—ligaments or fasciae, recognizable by ecchymosis, loss of function and pain, the symptoms of which are both subjective and objective

- 3 A sprain-fracture is, in the milder form, recognizable only by roentgen-ray examination, in the severer form it is recognized as a part of the pathology of dislocation

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<sup>7</sup> Ross, G G, and Stewart, M D A Study of Sprain Fracture, *Ann Surg* 55 71, 1912

In the milder form the crucial ligaments are involved, in combination with a strain or perhaps a sprain of the collateral ligaments, or injury to the menisci, in the latter both the collateral and crucial ligaments are involved, with different degrees of dislocation

In experiments in which stress was thrown upon the crucial ligaments in an anteroposterior direction, with a little outward or inward thrust, the resulting injury, due to pull upon the crucial ligaments, demonstrated that one of three things might happen (1) rupture or laceration of a crucial ligament, (2) fracture of the tibial spine, and (3) fracture of a femoral condyle by avulsion, through pull on a crucial ligament at the point of insertion. These three elements I shall call the crucial triad

Dissections showed a minimum amount of damage to the collateral ligaments, with no objective evidence of injury.<sup>7</sup> The roentgen ray demonstrated that a sprain-fracture was present

Ross and Stewart<sup>7</sup> state that about 15 per cent of all fractures are sprain-fractures. In the past many cases of fracture have passed unnoticed under the diagnosis of "severe sprain of the knee"

Preston<sup>8</sup> considers that fracture and avulsion of the tibial spine are due to pull of the crucial ligaments and are a complication of dislocation of the knee, and that avulsion of the spine occurs in lieu of rupture of the ligaments

Stimson<sup>9</sup> says that avulsion of the tibial spine was known only as a complication of dislocation of the knee before the introduction of the roentgen rays, and says further that recently several cases have been recognized by aid of the roentgen rays in much slighter injuries of the knee joint, in the so-called sprains and twists. He refers to Lange's<sup>4</sup> article

Robert Jones<sup>2</sup> states that rupture of the crucial ligaments and fracture of the spine of the tibia occur as the result of forcible twisting of the knee without sufficient displacement occurring for the case to be diagnosed as a dislocation of the knee

The cases cited by Lange show that twisting of the knee played an important part in the mechanism of the injury, and demonstrate that sudden and severe strain to the knee joint is capable of producing injury within the joint, with negative evidence of bruising or any signs of fracture, not only in the cadaver but in the living subject as well. Lange calls attention to the fact that in his Case 3 the strain was borne chiefly by the crucial ligaments, resulting in avulsion of the spine

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8 Preston, M. E. *Fractures and Dislocations*, St. Louis, C. V. Mosby Company, 1915

9 Stimson, L. A. *A Practical Treatise on Fractures and Dislocations*, Ed. 6, Philadelphia, Lea & Febiger, 1910

of the tibia His Case 4 was complicated by the fact that the strain was apparently felt by the tibiofemoral collateral ligament which tore off its femoral (medial condyle) attachment This was followed by stress on the crucial ligaments as shown by the injury

In Callender's case of the boy, 12 years old, who fell on some ice and struck his right knee a severe blow over the medial condyle, twisting his leg in his fall, final results showed avulsion of a fragment of bone from the medial surface of the lateral femoral condyle at the point of insertion of the anterior crucial ligament Twisting played an important part in the mechanism of the injury in the three cases just cited It is through this twisting that tensile stress in the direction of the longitudinal axis of the anterior crucial ligament is brought about

It makes no difference whether the femur is carried forcibly backward and a little outward, or whether the tibia is carried forcibly forward and a little inward with twisting, for under the remarks on surgical anatomy it was stated that in flexion the tibia rotates inward, and when this occurs under sudden stress with the leg undergoing flexion, sudden and heavy stress is thrown upon the anterior crucial ligament, for it is probable that the tibia moves forward as well as rotates inward It has been stated above that the whole mechanism of injury is variable and complex, depending upon the individual peculiarities and combinations of irregular muscular activities, so that it is impossible to determine the details attending the accident These activities modify the results of pure violence in manifold ways

The case cited by Ross,<sup>6</sup> and quoted above, regarding the ensign on the U S S *Douglass*, agrees in a most gratifying way in illustrating that force applied over the upper and back part of the leg, driving the tibia forward, as demonstrated in the experiments given above, will produce fracture of the tibial spine Even the pad was present in the folded top of the rubber boot The exact details of the mechanism of production are not known as is always the case

The consideration of the foregoing cases is sufficient to prove to a certain extent, at least, my findings in experimental work

#### SUMMARY

The foregoing resume and results of experimentation appear to warrant the following statements

- 1 Variation in the anatomic constituents of a part must be considered These affect size, strength and length, and are often a part of a peculiar body habitus

- 2 Variations in anatomic structures may predispose the individual or part to injury from less forcible degrees of stress than are ordinarily capable of producing such injury in parts of optimum stability

3 Injuries to the knee joint which may appear slight or trivial are occasionally accompanied by a crucial triad involvement

4 All injuries to joints should be considered seriously, not only for the sake of possible strain, sprain or sprain-fracture, but as forming a point of least resistance

5 Sprain-fracture of the knee joint may be present without giving objective symptoms. Roentgenograms reveal the fracture

6 Rupture of a crucial ligament may be present without giving objective symptoms, except as stated under paragraph 16, and is not shown by roentgenograms

7 Experimental fractures of the spine of the tibia agree closely in character and mechanism of production with actual clinical cases

8 Sprain-fracture or rupture of ligaments occurring consistently in experimental procedures on the cadaver afford the most positive proof of the fact that injuries are permitted to occur in this way, failure to demonstrate such injuries in experimental tests on cadavers means nothing (Ross)

9 Experiments on the cadaver have demonstrated that force applied over the distal and anterior surface of the thigh (femur), driving the femur backward on the tibia when the leg is fixed, will produce rupture of the anterior crucial ligament (greater force rupturing both crucials), and fracture of the tibial spine anteriorly or avulsion of a fragment of bone from the femoral condyle at the point of insertion of the ligament, resulting in crucial triad involvement

10 Experiments on the cadaver have given direct proof that similar results may be obtained when the tibia is driven forward by force applied to the upper and posterior part of the leg, driving the tibia forward on the femur, the thigh being fixed

11 Inward rotation of the leg (tibia), when it is more or less flexed, may result in injury to the lateral meniscus or may involve an element of the crucial triad

12 Inward rotation of the leg may be accomplished by direct action of the muscles (sartorius, gracilis, etc.) or by mechanical violence

13 Outward rotation of the leg (tibia), when it is more or less flexed, may lacerate the medial meniscus, or involve an element of the crucial triad

14 Outward rotation of the leg is accomplished by action of the biceps femoris muscle, or by mechanical violence

15 Violence applied laterally to the knee results in a complicated injury—fracture of femoral condyles, tibial tuberosities or fibular head, crucial triad involvement, with dislocation of the knee in any degree according to the character of the violence

16 When, after an injury to the knee, it is found that the tibia can be displaced backward or forward, or rotated inward in the extended position, an injury of one or both crucial ligaments may be diagnosed. Such patients complain of preternatural mobility and insecurity in the knee (Robert Jones <sup>2</sup>)

17 When in the extended position the tibia cannot be displaced forward, it may be assumed that the anterior crucial ligament is not torn across. If in full flexion the tibia cannot be displaced backward, the posterior crucial ligament is not ruptured (Robert Jones <sup>2</sup>)

18 It should be borne in mind that no two injuries are exactly alike, either in pathology or in mechanism of production, that the results are the outcome of complicated interactions at a critical period of time, of external violence, individual peculiarities and complex spasmodic muscular actions, and that diagnostic statements are but guides to individual deductions in each particular case of injury that is of clinical interest.

# OBSERVATIONS ON THE CORRECTIVE AND OPERATIVE TREATMENT OF STRUC- TURAL SCOLIOSIS \*

ARMITAGE WHITMAN, M D

NEW YORK

In summarizing three years' experience in the treatment of structural scoliosis of unknown cause, it has seemed best to begin with a short discussion of scoliosis in general, and of the theory and practice of its treatment, in order to make clear the gradations which finally led to the introduction of the operation. It must be understood that the experiences on which these remarks are based are, with one exception, those of hospital practice. If the subject of scoliosis appears to be taken seriously, it is because the cases I have seen are serious and are so regarded by the patients themselves.

Among the most discouraging subjects with which orthopedic surgeons have to deal is rotary lateral curvature of the spine. It is not necessary in an article of this character to make an exhaustive catalogue of its well known causes. The most common and important are various diseases of the nervous system, rickets, empyema, torticollis, and vertebral malformations. Less common are inequality in the length of the legs, astigmatism, general muscular insufficiency—in general, anything which affects the balance or symmetry of the body.

Aside from these cases, to which a cause may definitely be assigned, there remains a large and extremely important class in which I am particularly interested—scoliosis of unknown origin, or, to use a term which I shall employ for the sake of brevity, "idiopathic scoliosis."

There have been many theories advanced as to the etiologic factor in this group. Some believe it to be unrecognized anterior poliomyelitis, others, malformations of the fifth lumbar vertebra, and still others, slouchy posture, or the persistent assumption of a faulty attitude.

I have examined all the cases in this series for evidence of anterior poliomyelitis, and have not found it. In cases in which scoliosis is definitely caused by this disease, it is originally overlooked because the unilateral abdominal paralysis, or weakness, which is usually its cause is not sought for by a methodical routine examination, and often escapes attention. It may, however, subsequently be demonstrated if present.

Malformations of the fifth lumbar vertebra have not been observed. No two surgeons can be found who will agree as to what the roentgenographic appearance of a normal fifth lumbar vertebra should be. Aside

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\* From the Hospital for the Ruptured and Crippled, service of Dr. Royal Whitman.

from this difficulty, however, there is the theoretical objection that a curvature arising from such a source should be the response to a constant variation, and that, the source remaining the same, the variation should proceed to a point of compensation and there cease. I think that no one would venture to say with certainty when a given case of scoliosis had arrested its progress.

All authors mention undernourishment, poor muscular tone, slouchy attitude, in other words, the physically sloppy persons, as being typical subjects of the deformity. Oddly enough, however, I have not observed



Fig 1—Left, back before treatment, right, side view before treatment

this to be so. All girls nowadays are under the influence of the debutante slouch, the attitude in which the abdomen becomes the most prominent feature. The patients in my series, as will be seen from their photographs, were neither particularly sloppy nor particularly weedy.

All that we are entitled to say of this class of cases, therefore, is that girls are evidently far more commonly affected than boys, and, as it is very uncommon in quadrupeds, that it is probably largely a fault subsequent to the assumption of the upright attitude.

The type of patient with whom we are dealing, then, is a girl between the ages of 12 and 16 years, presenting a fixed, or structural scoliosis,



a deformity which cannot be corrected by a change of attitude, and in which the normal structure of a vertebra, or vertebrae, has already been altered. We are dealing, therefore, with a condition of whose origin we are practically ignorant, and of whose course in a given case we are uncertain.

#### VARIOUS CORRECTIVE METHODS

Since the time of Hippocrates, various methods of correction have been attempted—exercises, and apparatus applied with the patient suspended, with the patient prone, with lateral traction, and with direct pressure on the ribs. Dr. Abbott, at length, introduced an important variation in that he worked on the principle that the spine was more easily rotated—untwisted—in the attitude of full flexion, when the articular processes were thus separated as far as possible. Once the rotation was corrected the straightening of the lateral deformity would be easy. He also emphasized the necessity of maintaining overcorrection until accommodative changes in the spine had taken place. In practice, at least in the experience at the Hospital for the Ruptured and Crippled, this did not prove as simple as it sounds. The patient was often sacrificed to his curvature, and the secondary deformities, muscular atrophies and pressure sores resulting from the corrective jackets might leave the last state of the patient worse than the first.

The insuperable obstacle to efficient treatment of this deformity is that in any ambulatory treatment we are forced to attempt to straighten a tree by applying pressure to its branches. There is another horticultural principle in the background—a growing plant, such as a cucumber, introduced into a vessel, will in time, with the process of growth, adapt itself to the shape of the vessel. In other words, applying straight plaster-of-Paris jackets to a growing body will in time induce the body to grow straight.

We are hampered by the fact that the deformity to the average patient does not present itself as a condition requiring surgical care and that its treatment must be confined within those limits to which the patient will consent. In the majority of cases it must, therefore, be ambulatory.

In the cases in question, however, there has been one point favorable to the success of the treatment, namely, that the patients, between the ages of 12 and 19, came to the hospital voluntarily because they were concerned about their unsightly appearance, and therefore they did not have to be browbeaten or persuaded to undertake a treatment of considerable severity.

As a reaction against the unpleasant secondary effects of the Abbott treatment, Dr. Whitman suggested the application of plaster-of-Paris jackets with the patient suspended, and in full extension and rotation



Fig 2—Patient suspended, heels just touching ground, showing preliminary felt padding and direction of pull of traction bands

This treatment has gradually been modified and the rotation largely given up. The jacket is now applied with the patient suspended, in full extension, with traction, and pressure over the protruding ribs. A large window is cut out over the hollow side, to encourage the expansion of the chest. The high shoulder is included in the plaster to hold it



Fig 3—Preliminary padding, showing band pulling in oblique direction directly against convexity of ribs, also assuring hyperextension of spine

down and the plaster carried as high as possible under the arm on the low side to throw the body in the reverse direction. The patient is never allowed to stand or sit unsupported, even when the jackets are being changed.



Fig 4—Jacket applied

The full details of the application of this type of jacket are presented in Dr Kleinberg's article<sup>1</sup> One modification of the treatment he describes has been introduced I have had a third upright added to the frame in which the jackets are applied This bar moves from a fixed point midway between the other two and may thus be placed at



Fig 5—Jacket applied

any point on the circumference of a half circle By this means, the traction is made on a line directly antagonistic to the point of greatest curvature of the ribs It also aids considerably in assuring hyper-extension of the spine

<sup>1</sup> Kleinberg, S Scoliosis, Surg Gynec & Obst 32 364 (April) 1921

Dr Lovett<sup>2</sup> objects to suspension on the ground that no one attempts to straighten a bent stick by pulling on its ends, and that the greater the tension thus produced, the more ineffective must be any attempt at lateral bending. On the other hand, no one would be condemned for trying to straighten the warped shaft of a golf club by hanging it up in a moist atmosphere with a weight on its end. These considerations are more or less theoretical. Practically, however, we have experienced an objection to the application of jackets in the prone position, in that they are likely to be exceedingly uncomfortable, and to necessitate the patient's lying down at frequent intervals. We consider the advantage of the present method to be that, up to the final stage, the treatment is entirely ambulatory.

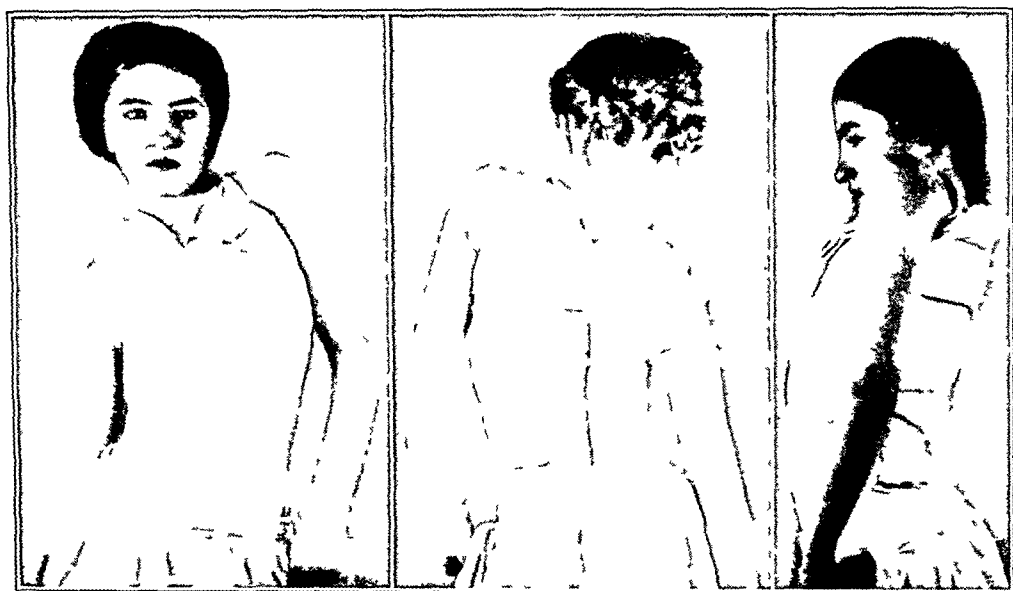


Fig 6—Left, completed jacket, center, showing extent of fenestrum elevation of low shoulder, complete obliteration of original convexity on the right side, right, side view

Although theoretically, and in accordance with the experiments of Dr Lovett, the spine is perhaps locked in extension, clinically we have by this means succeeded in considerable correction of the curvature, as shown by the roentgen ray, and, what is more important, in great improvement of the external appearance of the trunk, the matter about which the patient herself is chiefly concerned. One patient, coming from West Virginia, and thus at a disadvantage as regards supervision, found the treatment exhausting, lost weight and was forced to abandon it. The others have gone about their ordinary pursuits, and in most cases their general condition has noticeably improved. The gain in height and the improvement in color and complexion have been striking. The

<sup>2</sup> Lovett R W Lateral Curvature of the Spine and Round Shoulders, Philadelphia P Blakiston's Son & Co 1907 p 129

jackets are changed at intervals of two months. There has been one small pressure sore, which did not necessitate the removal of the plaster.

The use of the corrective jackets is kept up, naturally, as long as correction of the curvature, as shown in the roentgenogram, is seen to be progressive. In one case, of a long single curve, the condition has been fully corrected. Here let me emphasize, however, that "fully corrected" means simply that, according to the roentgenogram, the lateral curvature of the spine has been corrected. Anatomically, I doubt whether the rotation has been at all affected, except as it is influenced



Fig 7—The convex stretcher frame, with traction on the head and pelvis, used before and after operation

by the extension, and I believe that the external improvement in the appearance of the trunk is due simply to the lengthening of the spine and to the pressure of the jacket on the more or less elastic ribs.<sup>3</sup> Usually, however, the typical right dorsal curve will improve up to a certain point, and there remain, further attempts at correction causing only exaggeration of the curves above and below it, which is useless and undesirable.

<sup>3</sup> Dr Kleinberg tells me that he has observed by the roentgen ray apparent complete correction of the rotation in two cases. In both of these cases there was subsequent relapse.

## THE FUSION OPERATION

One is then faced with the problem of what to do next. If a straight jacket, removable plaster corset, or a brace is applied, the patient will relapse to a greater or less extent. The correction of the spine can be maintained only by the jacket, applied in the deforming attitude, which is repugnant to the patient. The prospect of wearing



Fig 8—Left, back four months after operation, right, side view after operation

apparatus for from two to four years, while the accommodative changes in the spine take place, is not alluring. In seeking an exit from this situation, I became interested in the fusion operation on the spine, as performed by Dr. Hibbs. The method has also been resorted to by nature in cases of spinal caries.



Theoretically, the argument for the operation would be this. We may assume, except in the case of curvatures developing from perfectly well known causes, and in cases of long single curves, that there is originally a primary curve, in response to which, in order to maintain the balance of the body, a secondary curve develops. If we can, by any means, check the progress of the primary curve, the secondary curve should have no excuse for progressing. Also, by providing a certain area of stiffness, one might facilitate muscular control, on the principle that it is easier to balance a stick than a rubber tube.

On the basis of this theory, then, the operation was proposed. Curiously enough, the first patient was the sister of a girl who had been

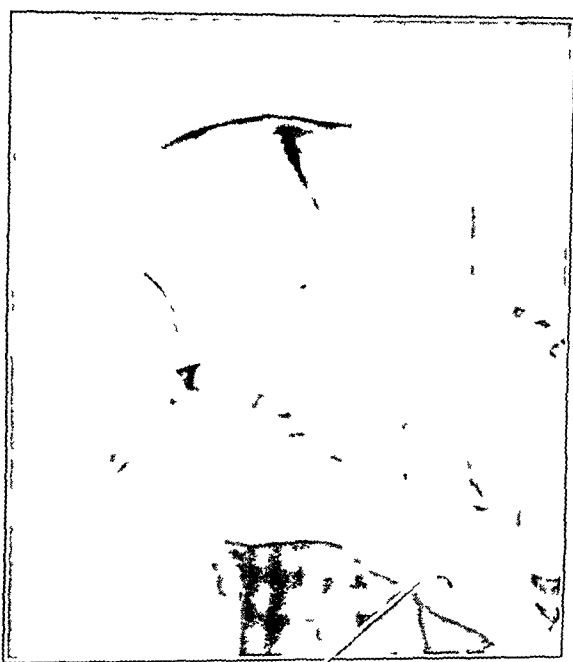


Fig 9—After operation, patient bending forward to show the obliteration of the convexity of the ribs

treated at the hospital by the Abbott method for four years, absolutely without success, and had eventually developed the most extreme deformity. She was, therefore, alive to the importance of her condition, and peculiarly intelligent as to the rationale of treatment. It was explained to her that the operation was a new departure, at least at the Hospital for the Ruptured and Crippled (and I believe Dr Hibbs and Dr Forbes have confined themselves to cases of paralytic origin) and entirely experimental in character. She was told that the spine having been corrected up to a certain point and the external symmetry of the trunk practically restored, the operation was performed for the purpose of internal, rather than external, plinting, to maintain the degree of

correction In other words, it was a choice between operation and the wearing of a brace, jacket or corset for between three and four years

The operation was performed in June, 1920 The patient was then placed in a plaster shell, and two weeks later a corrective jacket was applied, which she wore home Unfortunately, the correction was a little too successful, in that, when the spine stiffened, it maintained the elevation of the previously low shoulder, although no such correction can be seen in the roentgenogram This, however, is not evident on casual inspection, and is of no importance Plaster jackets were worn for four months after the operation Since October, 1920, the patient has been without support The dorsal spine appears stiff, there has been no appreciable increase in the deformity, either externally or roentgenographically, the patient looks well, and is satisfied with the result Her influence has been strong in urging other patients to submit to operation

Since July, 1920, I have operated on fifteen patients, and the routine of treatment and the details of the operation have been varied It is now the practice, on removal of the jackets, to place the patients on the convex stretcher frame for a few days previous to the operation, to allow them to become accustomed to the frame, and to provide opportunity for thorough cleansing of the skin Following the operation, the patient is placed directly on the frame and there remains for two months As soon as the postoperative discomfort has subsided, traction is applied to the head and pelvis, gradually increased to as much as 20 pounds (9 kg) on the head and 30 pounds (13.6 kg) on the pelvis I do not feel that the traction is of any particular importance except as a means of assuring the immobility of the patient The frame itself assures hyperextension of the spine, the position in which residual deformity, if present, is least evident, and encourages chest expansion, and the pressure of the body weight is of service in reducing the protrusion of the ribs We have also lately, both before and after operation, applied traction in an anterolateral direction against the convexity of the ribs in the manner employed during the application of the jackets This seems to be of real service in reducing the apparent deformity

The operation is, as a rule, accompanied by considerable shock, depending a great deal, of course, on the time consumed in performing it This has varied from an hour to an hour and three-quarters The patient's position places the anesthetist at a disadvantage In two cases, it has been necessary to remove the patient from the frame during the night following the operation One can think of no theoretical reason for this removal, but practically putting the patient in his accustomed environment—bed—seems to soothe and reassure There have been no deaths and no infections

I have been surprised at the lack of pain following the operation. I discovered one patient, on the eighth day, turned on her face, propped on her elbows and conversing with a visitor. I was at first troubled by the amount of movement permitted on the frame, but have lately solaced myself with the idea that, as asserted by the advocates of the treatment of fractures by traction and suspension, a certain amount of movement might tend to an exuberant callous formation. It is my impression that the patients on the frames have stiffened more quickly than the ones who were placed at once in plaster.

The patient remains on the frame for two months, by which time stiffness of the area of operation seems established. A short straight jacket is then applied, to maintain the balance of the trunk, and to prevent the area of operation from being subjected to any strain, in the same way in which one would wish to protect a fractured femur for some time after bony union appeared firm. This jacket is worn for about two months. Some patients are then able to go without any support whatever. In others, it will be found that the long period of external support and inactivity of the spinal muscles, usually about eighteen months, has so weakened the area untouched by operation that the patients suffer considerably from weakness and backache. In such cases, we apply a brace or corset, and institute graduated exercises for the weakened muscles.

The operative technic has been gradually worked into a combination of the Hibbs and Forbes operations. The periosteum is carefully removed, and a thorough attempt is made to destroy the intervertebral articulations, as in the Hibbs operation. The laminae are then more roughly treated than in Dr. Hibbs' procedure, several sections of bone being pried up on each side. The spinous processes are split horizontally and vertically, and bent upward and downward, providing very satisfactory interdigitation. The ligaments are united with chromic gut. I must say that the variations in the operative technic have been caused by the inward promptings of the operator who wished to perform as apparently thorough an operation as possible, rather than by any unsatisfactory results from either of the original technics.

#### CONCLUSIONS

This treatment, it will be seen, develops as the result of a discouragement with all previous methods. Its effect, by providing opportunities for observation on the exposed spine, has been more discouraging still. I have found in backs in which, according to the roentgen-ray examination, the lateral curvature was almost, or entirely, corrected, a surprising degree of rotation persisting. A patient of 14 years, under treatment for more than a year, in whom the deformity had been noticed only a few days before admission to the hospital, had, at operation, a very marked

rotation and distortion of the vertebrae Force sufficient to fracture a spinous process has been applied on several occasions without having the slightest effect on the rotation, and that following removal of all the posterior ligaments of the spine, with the patient prone and anesthetized How, then, may we expect, anatomically, to correct deformity of the spine by any ambulatory treatment, and when all the force we are able to exert can be applied only to the ribs? It is conceivable that prolonged rest on the stretcher frame might correct the deformity, but I can conceive of no patient who would submit to such an indefinite prolongation of recumbency

This experiment might be of interest in connection with the operation proposed in January, 1894, by Dr Shaffer,<sup>4</sup> who suggested operating in early cases, by severance of the costotransverse ligaments and any other opposing structures, then, by actual instrumental force applied to the transverse processes, reducing the malposition of the vertebrae, a procedure which he evidently considered analogous to a subluxation

Neither can I agree with the conclusions presented by Dr Hoke,<sup>5</sup> who believed that by removal of a section of the ribs, first on one side and then on the other, he might more easily, by force, correct the malposition of the vertebrae According to his published case, he did succeed in improving the external appearance of the thorax, but whether any alteration in the position or structure of the vertebrae was accomplished is doubtful This opinion is sustained by the fact that I can find no further reference to the operation since Dr Hoke's original article appeared, in 1903

I will not even say that I am sure that ankylosis has been obtained in every case I think it has, but the difficulties of judging of movements of the dorsal spine are so great that the presence or absence of motion must rest largely in the desire, subconscious or otherwise, of the examiner Sufficient stiffness, however, has been obtained to limit forward bending, and thus to conceal the protrusion of the ribs, the most objectionable feature of the deformity There has, so far, been no increase in the deformity, either as shown by roentgen-ray examination, or in the estimation of the patient One may mention also that there can be no class of cases in which the opinion of the patient is of more value The patients apply for treatment because they are concerned about their unsightly appearance, and there can thus be no keener critics of the cosmetic effect It is unfortunate that neither necropsy nor second operation has provided opportunity actually to inspect the result

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4 Shaffer *Am Med-Surg Bull*, Jan 1, 1894, p 51, Feb 15 1894, p 236

5 Hoke *Am J Orthop Surg* 1 169, 1903

Judgment of the existence of ankylosis by the roentgen ray is unsatisfactory and misleading. A good lateral picture will sometimes show the continuous bridge of bone formed by the fractured spinous processes, but anteroposteriorly one sees nothing except obliteration of the facets of the articular processes and slight obscuring of the intervertebral disks. Naturally, one would not expect them to be altogether invisible, as no bony deposit could be as thick as the vertebral body.

A discouraging feature of the deformity is the fact that the side of the chest on which the ribs project is already the narrow side, and that pressing on the ribs to reduce obvious deformity makes the chest narrower still. This is a disadvantage which is somewhat alleviated by the frame treatment, in which the chest has every opportunity to expand.

The three years' work in the treatment of rotary lateral curvature of idiopathic origin has thus resulted in a curious mixture of optimism and pessimism. I am convinced that the anatomic cure of the deformity by any means hitherto devised is impossible. A certain proportion of fairly well advanced cases, particularly of long single curvatures, may be markedly improved in external appearance, and their curvatures, as revealed roentgenographically, much reduced by the type of jacket we are now applying. It seems that the degree of improvement thus acquired might be maintained by some type of fusion operation in the area assumed to be that of the primary curve. The objection may be advanced that the cases are too recent to be judged as end-results, but, on the other hand, the patients have practically all attained full growth, so that future development cannot have much influence on their course, and surely one would expect that, if the deformity were to progress, its progression would be most rapid immediately following the removal of the jacket, in the period when the security of the fixation is most doubtful and general weakness and muscular atrophy are most extreme.

The treatment is not one which will ever be applied to a large class of patients. It is somewhat exhausting to both patient and surgeon. It requires of the patient to an extraordinary degree the development of the "will to get well," and of confidence in the person conducting the treatment. It requires of the surgeon the knowledge, primarily, of what cases are susceptible of improvement by the treatment, the skill and experience necessary for the application of the corrective jackets, the persistence to apply them personally during long periods, and, finally, the acquisition of the rather difficult technic of the operation.

I am not in sympathy with the attitude of surgeons who publish reports of most difficult operative procedures, the results often of years of specialized effort on their part, and convey the impression to the casual reader that the reading of the article fully equips one for the performance of the operation. Such writers would privately admit that

such an impression was conveyed for the purpose of flattering the intelligence of their readers, but it seems surprising that they should esteem an audience of such implied intelligence worthy of the pains

It is to be hoped that no wave of enthusiasm will develop for the "operative treatment of scoliosis." It must be emphasized that the operation is the final step in a tedious process of correction, and that in principle it offers little that is new, unless it be the principle of balance on which it is performed. It must not be urged on the patient. In fact, throughout this kind of treatment, it is essential that the patients themselves be desirous of treatment. Such severe measures as are necessary cannot and should not be forced on an unwilling child. For an orthopedic surgeon to mention psychology will doubtless be provocative of more or less indulgent mirth, but none the less it is the most important factor in any form of treatment for scoliosis. The surgeon may labor with the body of a patient as much as he pleases, and obtain a physically good result, but unless he can persuade the mind that to stand up straight is desirable, his work will be a failure. There is no spine so crooked that its appearance cannot be improved by effort on the part of its owner, and, conversely, there is none so straight, artificially or otherwise, that it cannot by slouching be made to simulate deformity.

One is continually impressed by the futility of many conventional forms of treatment. Of what use are exercises for scoliosis if the patient slouches to and from the gymnasium? Of what use are exercises in the treatment of weak feet if the patient walks with his toes turned out? After all, the business of any mechanism is to function, and the function that is important is that involved in the ordinary occupations. The purpose of the foot is to make walking possible, not to be educated muscularly before a mirror. This factor, the mental control of a patient, is the essential one in any treatment involving anything except the giving of pills. Even pill giving, a regimen of comparative simplicity, may be a failure without the supervision of a third person.

No one regrets more than I the absence of the original photographs and roentgenograms of so many of the patients. I can only ask those who are acquainted with the trials of work extending over long periods of time to remember the facility with which roentgenograms and photographic plates are broken and lost. As no extraordinary claims are made, perhaps the absence of these important records is not of so great importance as it otherwise might be. Photographs may be easily disparaged as records in any case, as we all know how shadows and focal lengths may be manipulated to the advantage, or disadvantage, of the record. I requested the roentgen-ray department to make the photographs in standard poses and at the same focal distance, but was not present when any of them were taken. Trivial as some of the original

deformities may thus appear, to the patients their appearance was sufficiently repugnant to make them submit to months of plaster, operation, and, finally, two months on a stretcher frame

It has been suggested by some casual observers of these patients that none but mild cases have been selected for operation. This is not altogether true, but there is foundation for the suggestion. As has already been stated, the operation is only the final step in the course of a long process of correction. The patients were not selected with a view to their being operated on, but because it was thought when they first presented themselves that their curvatures were susceptible of improvement by corrective jackets.

In this series there is one case of extreme deformity in which operation was performed in the hope that the stiffening of the spine would relieve the pain and act as a substitute for apparatus. Unfortunately, this is the only one in which the end-result is not known. Four of the fifteen cases are too recent to report. The detailed report of eleven cases follows. Notes other than those made by me are followed by the name of the physician supplying them.

#### REPORT OF CASES

**CASE 1—History**—M. M., aged 14, schoolgirl, was admitted to the outpatient department of the hospital, April 29, 1920, with a history of measles, varicella, mumps, pertussis and influenza. The parents and brothers were healthy. The chief complaint was lateral curvature of the spine, of possibly three months' duration. The scoliosis was first observed by the school nurse about three months previously. It was noticed that the patient walked and sat with the right shoulder elevated, and was unable to throw her shoulders backward. On examination, the lateral curvature was found. Roentgen-ray examination was made, April 6, 1920. The rectal temperature was 99.4 F. A throat culture was taken (B. L. Schoolfield).

**Physical Examination**—May 1 (Dr. Whitman). The patient was in fair condition. She presented a moderate double curvature of the spine, most marked to the right in the dorsal region. There was compensatory deformity with but little rotation in the lumbar region. Instructions were given that a roentgenogram and photograph be taken and a corrective jacket applied.

**Treatment**—May 11. For the past forty-eight hours, the patient had been on a frame with 5 pounds (2.2 kg.) traction on each leg, and 10 pounds (4.4 kg.) on the head. The dorsolumbar curve and the very marked rigidity of the spine had almost disappeared, but there was now evident a very sharp, practically right angled, curve to the right between the second and fourth dorsal vertebrae. A roentgenogram embracing the seventh cervical to the fifth dorsal vertebra was made. The only discomfort caused by the treatment was redness and soreness under the chin, a difficulty which may be obviated by the use of a little extra padding.

May 13. The head sling had been applied in a new manner by Dr. Kau. One strap now passed over the forehead, the other behind the ears and was attached under the occiput. The patient was comfortable with the strapping applied in this manner.

May 18 The second roentgenogram revealed a very marked wedging of the third dorsal vertebra and malformation of the second and third ribs on the right side in the nature of an articulation between the two, about 1 inch (2.5 cm) distal to the point of articulation with the vertebrae. It was suggested that this malformation might be responsible for the curvature. But a week later Dr. Whitman stated that, in his opinion, the malformation of the ribs had nothing to do with the patient's curvature.

May 27 The deformity of the spine had decreased.

*Operation*—June 5 (Dr. A. Whitman, assistant, Dr. Purdy) An incision was made from the seventh cervical to the sixth dorsal vertebra, and the usual procedure of the Hibbs operation carried out. Considerable difficulty was

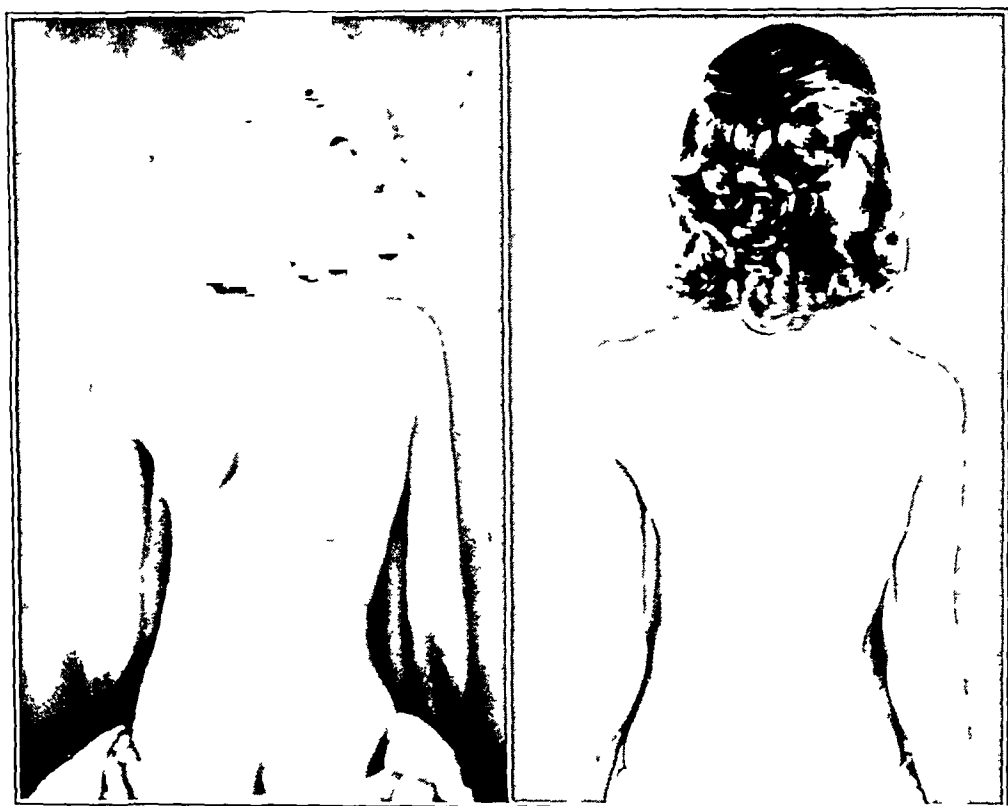


Fig. 10 (Case 1)—Left, before operation, right, after operation

experienced with oozing. At the level of the fourth dorsal vertebra on the right side, a pin point perforation of the pleura occurred. The muscle was at once allowed to fall over it. When the packing was removed ten minutes later, in order to finish the operation, there was no escape of air. No shock was noticed from this accident. The ligamentum nuchae was united with continuous plain gut. The skin was closed in the usual manner and a Calot jacket, which had been applied previously and cut off, was reapplied.

*After-Treatment*—June 17 The patient had a rise in temperature of 2 degrees following the operation, but no pain. Five pounds (2.2 kg) traction on the head and 19 pounds (8.6 kg) on the legs was applied about two days after the operation. There was no discomfort.



June 17 (p m) On removal of the shell, the wound was cleanly healed. With extension on the head and feet, the patient was suspended in bed by two bands of felt passed beneath the shoulders and hips and the Calot jacket was applied. A roentgenogram was made.

July 8 A second Calot jacket had been applied, July 6. The external appearance of the child's trunk was very good except for a slight prominence of



Fig 11 (Case 1) —Before operation. All the cases are right dorsal curves with the exception of Case 3.

the ribs on the right side. The spine in the region of operation appeared to be almost stiff.

July 8 The patient was discharged improved, and wearing a Calot jacket, with instructions to return August 5.

*Readmission* —September 7 The patient reentered the outpatient department.

September 11 The Calot jacket was removed. There was marked atrophy of the muscles of the back and scapular region. The spine in the region of

operation appeared perfectly stiff. Dr. Whitman and Dr. Kleinberg concurred in this opinion. Instructions were given that the child was to lie in bed and have gentle massage of the back muscles. A roentgenogram was made.

September 18. The roentgen ray revealed marked indistinctness of the intervertebral disks in the region of operation. The field of operation still

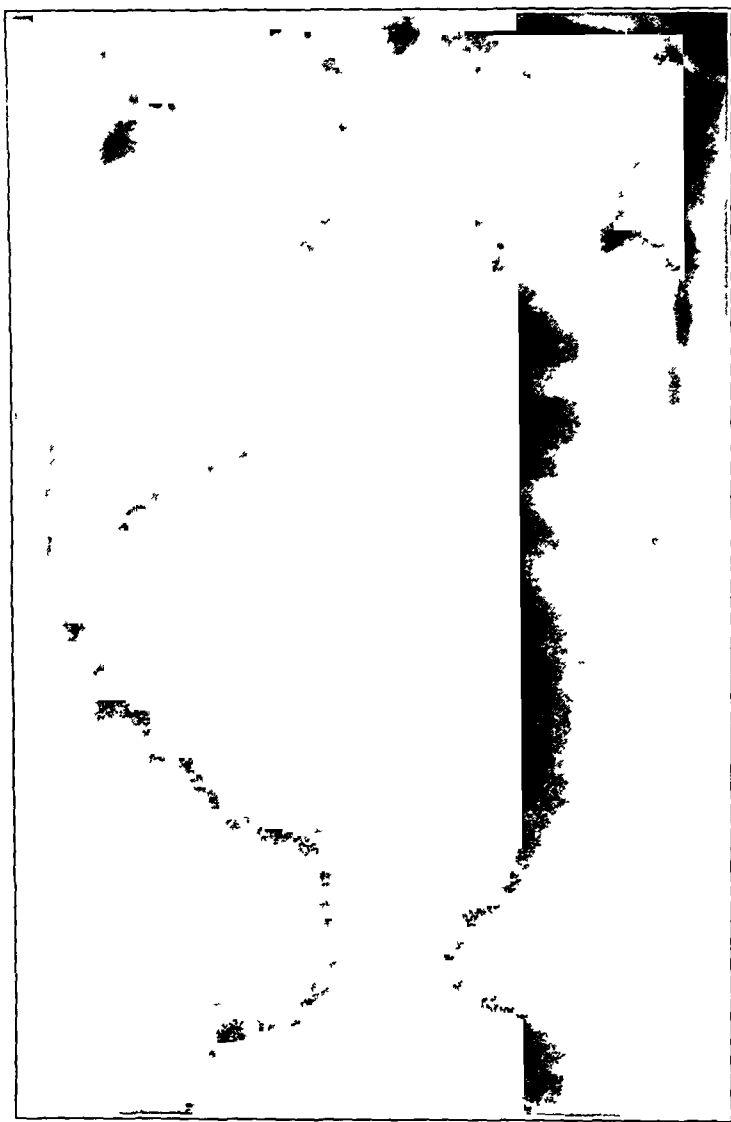


Fig. 12 (Case 1) —After operation

appeared perfectly stiff. The patient was discharged, with instructions to return in two weeks (October 2) for observation.

She was improved, and on discharge was without apparatus or plaster.

*Subsequent Course*—October 9. The child had been at home three weeks, going to school. She lay down during the noon hour, and took no exercise in the gymnasium. She was perfectly comfortable and the spinal muscles had

greatly increased in size and tone since the last report. No movement was discovered in the area of operation. A roentgenogram and photograph were taken.

March 17 (Dr. Whitman). As far as could be made out, the spine was rigid in the area of operation. The hips were of equal prominence, the shoulders level. There was still a prominence of the right scapula and a compensatory curve to the left in the lumbar region. It was the opinion of the patient, the supervising nurse and the family that the deformity had not increased since operation. A roentgenogram and photograph were taken.

April 22, 1922. The patient was in good condition. There was no increase of deformity.



Fig. 13 (Case 2)—After operation

CASE 2—*History*—I. P., girl, aged 14 years, had two brothers living and well, one sister with lateral curvature. Two brothers died in infancy, cause of death being unknown. The mother had had no miscarriages, and there was no tuberculosis in the family. The chief complaint of the patient was rotary lateral curvature, of fifteen months' duration. It was first noticed when the patient was being fitted for a dress, the summer of the preceding year, that the left hip was more prominent than the other, and the right shoulder was the higher. No angulation was noticed at this time. There had been no known poliomyelitis. The curvature was slight, right dorsal, when first noticed. It had progressed, and the preceding summer, angulation was first seen. The

patient had been under the care of Dr Kleinberg since the onset, taking exercises, but no cast was applied. The only symptoms were fatigue on slight exertion and severe pain in the region of the right scapula, not radiating.

*Physical Examination*—Nov 1, 1919 (Dr Whitman) The patient was in good condition, rather fat and heavy. She presented a marked fixed rotary lateral curvature involving the dorsal and lumbar vertebrae from about the seventh to the third. There was a slight compensatory curve above.

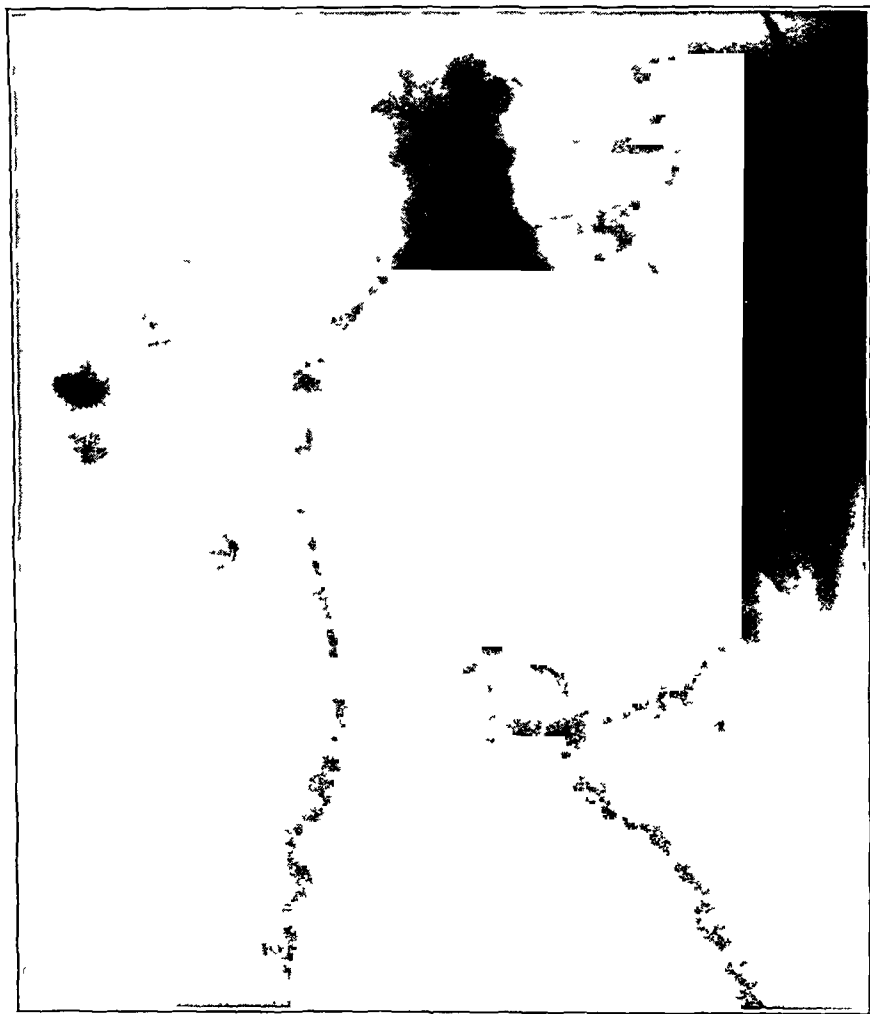


Fig 14 (Case 2) —Before operation

November 1 (Dr Kleinberg) The patient was a well built girl, presenting a right dorsolumbar scoliosis with a slight left lumbar compensatory inclination. The dorsal curve extended from the sixth dorsal to about the second lumbar vertebra. The shoulders were about on a level. The spine from the sixth dorsal to the second lumbar vertebra had a forward curve in contradiction of the often seen kyphoscoliosis. There was a backward displacement of the ribs on the right side, with the most prominent part of the deformity opposite to, or on the angle of, the scapula. On the left side, there was a moderate hollow.

The left "hip" was more prominent than the right. There was a moderate degree of rigidity. The anterior view of the chest was prominent on the left. The right side of the chest was flat. The anterior superior spines were on a level.

A roentgenogram made on October 25 revealed a moderate right dorsolumbar curve extending from about the fourth dorsal to the second lumbar vertebra, with the apex of the curve between the ninth and tenth dorsal vertebrae. There was increased separation of the ribs on the right and slight approximation of the ribs on the left side. The ribs on the left side were practically horizontal instead of inclined downward as in a normal person.

*Readmission*—November 6. After several days at home, the patient reentered the hospital to have the plaster-of-Paris jacket applied. It was intended to have the patient in suspension, in the erect posture, with the left shoulder elevated and the right pulled backward.

*Treatment*—November 7. An attempt was made to apply a Klenberg jacket, but when the procedure was half finished the patient became hysterical and finally fainted. The plaster was removed and she was returned to the ward to await another attempt (T. A. Willis).

November 11. A corrective plaster jacket was applied by Drs. Klenberg and Armitage Whitman. The patient had several fainting spells during the process and vomited freely (T. A. Willis).

*Second Readmission*—July 16. The patient had worn a plaster-of-Paris jacket since it had been applied in the outpatient department. Her condition had steadily improved under this treatment. She entered the hospital for an operation to maintain correction of the deformity (Dr. Schwartz).

July 17. From the general appearance, the girl was in good condition. There was no discharge from the ears and nose. The pupils reacted to light. The lymph nodes, cervical, axillary, epitrochlear and inguinal, were not palpable. The knee-jerks were equal. The examination of heart, lungs and abdomen was prevented by a jacket extending from shoulders to pelvis (Dr. Schwartz).

*Operation*—July 20 (Dr. A. Whitman). An incision was made from the third to the eleventh dorsal vertebra over the spinous processes. There was at least one-half inch (13 mm) of subcutaneous fat. The tissues over the tips of the spinous processes were incised, and the periosteum split and stripped away from the spinous processes with a periosteal elevator. Interrupted double catgut sutures were then taken about one-half inch (13 mm) lateral to the midline, between the spinous processes and slightly overlapping each other, with the idea of controlling the hemorrhage that usually follows division of the interspinous ligaments. The tissues were then divided and the periosteum stripped back from the laminae and for a distance of about one-quarter inch (6 mm) outward on the transverse processes. The fifth, sixth and seventh dorsal vertebrae were found rotated through an arc of about 45 degrees. With a curved chisel, slivers of bone were removed from the transverse processes to make a continuous bridge between the vertebrae after the articular processes had been gouged out with a curet. The spinous processes were then partially fractured at their bases and overlapped, shingle fashion, so that the tip of the upper processes came in contact with the fractured base of the one below. The vertebrae from the third to the eleventh dorsal were thus treated. The operation was difficult because of the thickness of the muscles and the resultant depth at which it was necessary to work. The ligaments were united with interrupted kangaroo sutures, the subcutaneous tissue with continuous plain gut, the skin with plain

gut The amount of hemorrhage was slight compared to that encountered in previous operations A posterior plaster shell was applied The duration of the operation was one and a half hours

July 22 Following the operation, the patient complained of pain in the upper dorsal region

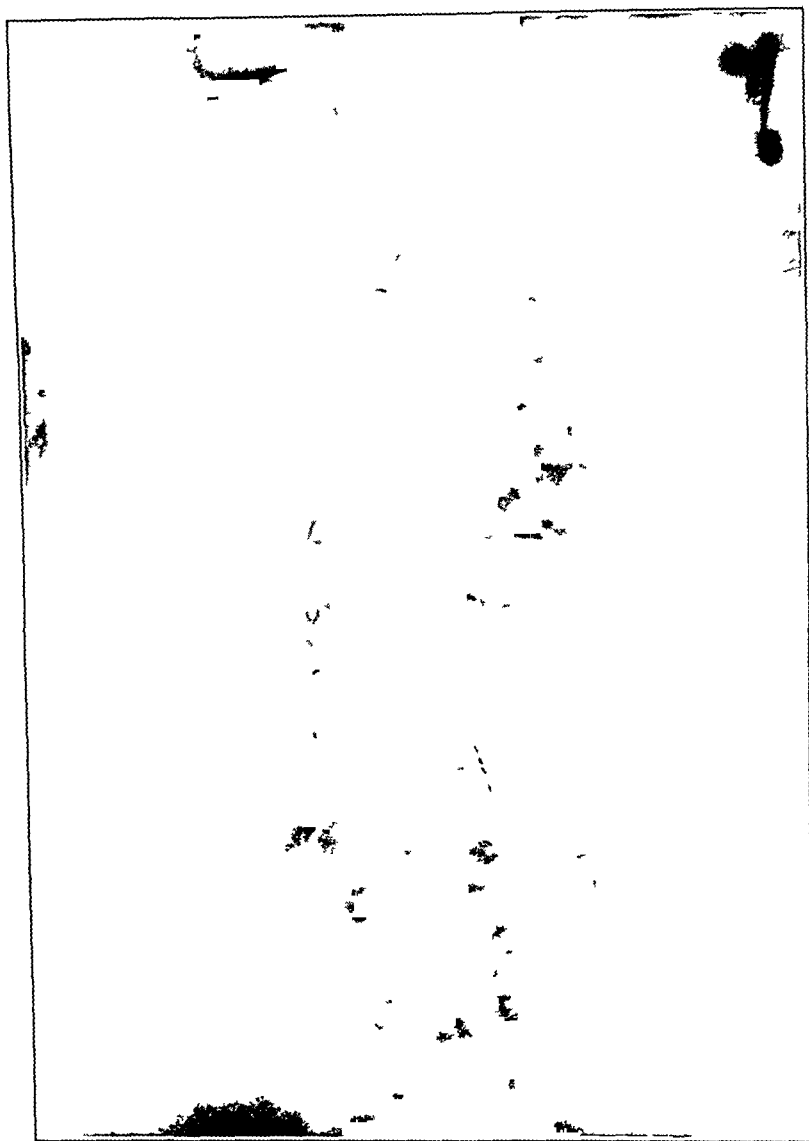


Fig 15 (Case 2) —After operation

*After-Treatment* — July 29 On the seventh day following operation, an attempt was made to apply a jacket with the patient suspended She suffered what has been variously diagnosed as hysteria or syncope, with very rapid pulse cold clammy skin, and involuntary movements On this occasion, the attempt had to be given up The patient's great weight and nervous disposition made it practically impossible to apply a jacket in a horizontal position Instructions were given that she remain in bed in a posterior shell

August 12 A jacket was applied, including both shoulders. The patient suffered an hysterical attack.

August 19 The plaster had slipped up, so that the shoulder straps were of no use. The patient was allowed to sit up. Roentgen-ray examination showed the disappearance of intervertebral disks from the third to the eleventh vertebrae and there was slight indistinctness of outline, as of bony proliferation.

September 23 The patient was discharged, improved, wearing a plaster jacket. She was instructed to report for further treatment (V W Purdy).

*Third Readmission*—October 19 The patient was readmitted to the outpatient department.

October 21 The external appearance of the trunk was normal. A roentgenogram taken October 20 showed an apparent fusion of the spine from the third to the eleventh dorsal vertebra. The intervertebral spaces were still visible, although the mass of the fused area was evidently denser in the mid-dorsal than in the upper and lower extremities.

On examination, no movement could be made out in the dorsal spine. Both forward and lateral bending were very much restricted. This opinion was concurred in by Dr Kleimberg. A roentgenogram was taken with the patient in the upright position and she was allowed to sit up for gradually increased periods each day.

November 4 The patient was discharged, wearing a plain plaster jacket. She was in good condition (Dr Nicola).

December 16 The plaster-of-Paris jacket was removed, and the patient was instructed to return in a week. A roentgenogram and photograph were taken.

*Outcome*—December 23 The patient had been without the cast for a week. There was no increase in deformity. There was apparently no anteroposterior mobility in the region of operation. The question of lateral mobility was doubtful. The patient was well satisfied with the result. She was instructed to report in two weeks.

March 5, 1921 A roentgenogram taken January 21, when compared with that taken Dec 16, 1920, showed no change in the deformity. There was a considerable increase in the density of the area of operation. No trace of the intervertebral disks was now seen between the fourth and tenth dorsal vertebrae. The appearance was of a solid bony mass.

July 23 The condition was very satisfactory. The spine appeared stiff and there was no increase in the deformity. The left shoulder was much higher.

July 26 A roentgenogram taken July 23 revealed no increase in the deformity. It offered also interesting testimony as to the fallibility of roentgen-ray evidence, as the roentgenogram taken May 14 appeared to show much greater density in the fused area. Four different observers thought the last plate was the first.

April 25, 1922 The condition was unchanged.

*CASE 3—History*—O P, girl, aged 12 years, entered the hospital July 6, 1920, with a clinical diagnosis of right lateral curvature. She had a history of measles, scarlet fever and whooping cough. Her parents and the other children were alive and well. The chief complaint was spinal deformity of eleven years' duration.

A physician called eleven years previously to treat the patient for fever recognized the spinal deformity. The treatment recommended was fresh air and a milk diet. Two years previously, a physician called to treat the patient for adenoids recommended a plaster corset for the spinal condition. The patient

wore a plaster-of-Paris corset extending from the pelvis to the sixth rib for six months. After removal of the plaster, the child was permitted to go four months without apparatus and then a leather corset extending from pelvis to hip was worn for six months, night and day. The condition had grown worse under this treatment. The corset was discarded because it caused pain. The child walked into the hospital without apparatus. She entered because of steadily increasing discomfort which she referred to the region of the left shoulder (Dr Schwartz)

*Examination*—July 8. The child was in good condition. She presented a most extreme rotary lateral curvature of the spine to the right in the cervical region, to the left in the middorsal, and again to the right in the lower dorsal



Fig 16 (Case 3) —Before operation

The head was carried forward practically to the limit of its capacity. There was extreme projection of both scapulae, and the razor back type of deformity of the ribs on the left side. The curve was rigid. There was a slight secondary deformity of the chest, and flattening of the upper part of the right chest below the clavicle, and prominence of the lower ribs on the left. The distance from the right anterior superior spine to the tip of the right internal malleolus was  $29\frac{1}{2}$  inches, the distance from the left anterior superior spine to the tip of the left internal malleolus was  $29\frac{1}{2}$  inches.

The child had a peculiar husky, brassy voice. A laryngeal examination was made to ascertain whether there was pressure on the recurrent laryngeal nerve, and a roentgenogram and photograph were taken. Instructions were given that the patient be kept in bed on a frame with traction on the head and pelvis.



July 27 The patient's deformity had been slightly, if at all, improved by treatment

August 21 There was no change in the upper dorsal region. Operation was decided on for relief of pain, and if possible to do away with the necessity for wearing a brace with a chin cup

Operation—(September 16, Dr A. Whitman) An incision was made over the spinous processes of the vertebrae from the first to the ninth dorsal vertebra



Fig 17 (Case 3)—After operation

The tissues over each spinous process were nicked. Double plain gut sutures were then taken 1 inch (2.5 cm) lateral to the spinous processes, including the tissues between the processes, and tied. This was done on both sides for the purpose of decreasing subsequent hemorrhage. The interspinous ligaments were then divided and the periosteum scraped back from the spinous processes and laminae. This was accomplished with great difficulty at both ends of the wound, owing to the forward bowing of the spine and the great amount of

rotation The vertebrae were very much distorted, the laminae on the left side being between one-quarter and one-half inch (6 and 12 mm) in width, and those on the right side scarcely more than one-eighth inch (3 mm) in width The laminae were gouged with chisel but the exact Hibbs technic could not be carried out because of the depth at which the laminae lay The spinous processes were then partially fractured and overlapped The periosteum and ligaments were united with kangaroo, the subcutaneous tissues with continuous plain gut, and the skin with plain gut The time of operation was one and a half hours The patient was then replaced on the frame and traction immediately applied

September 30 The wound had healed The patient was able to turn over on the frame without discomfort She stated that since the operation she had been conscious of less muscular tension drawing her head forward, and was able to move the head and neck with more freedom A Calot jacket was applied with traction across the shoulders in an anteroposterior direction, with the aim of further reducing the protrusion of the left shoulder The external appearance had been very much improved The patient was photographed in the Calot jacket

October 7 The patient was discharged, wearing a Calot jacket, and in good condition She was instructed to return December 2 (Dr Nicola)

October 7 The father said that the child seemed somewhat straighter and taller than before the operation Her general condition was much improved Her color and the general tone of the skin were now quite normal

*Readmission*—November 9 The patient had been in a Calot jacket since her discharge two months before She had been very comfortable She returned for roentgen-ray examination and further treatment The jacket was removed

November 11 There was a very marked improvement in the child's external appearance Her shoulders were apparently level, the prominence of the left shoulder was reduced about one half There was apparently stiffness of the spine A roentgenogram showed that the original curve had been improved almost 50 per cent There was a cloudiness of the shadows of the vertebral bodies, and obliteration of the intravertebral disks, in the operative region, giving an appearance of fusion The Calot jacket was applied Under other circumstances, felt pads would have been introduced in attempting to correct further the prominent scapula, but as the patient lived at a distance and could not afford to remain in the hospital, this was not done She was discharged, to return in a month for a change of jacket

*Second Readmission*—December 14 The patient again entered the outpatient department for observation

December 16 The plaster jacket was removed The improved appearance of the trunk noted at the previous readmission had been maintained There was apparent stiffness of the operative region The patient was placed on a frame Roentgen-ray examination was ordered

The patient was discharged wearing a Taylor brace with a chin cup, as her father objected to a Calot jacket She stated that since the operation she had been entirely relieved of the pain for which it was primarily performed

Oct 20 1921 The patient had not been heard from since she left the hospital All attempts to get in touch with her failed

CASE 4—*History*—A B girl, aged 13½ years, entered the outpatient department Oct 1 1920 with a clinical diagnosis of rotary lateral curvature of the spine She had had pneumonia at 4 years The father and mother were living

and well, as were two sisters. One brother died of pneumonia at the age of 6 months. The chief complaint was curvature of the spine, first noticed in the summer of 1919, the child complaining first of tired back. The mother observed a slight curvature, which continued to grow worse. The patient came to the clinic in February, 1920, and a plaster jacket was applied. She had worn the jackets for seven months, with frequent changes of plaster. After seven months, she was given a straight jacket which she still wore. She did not



Fig 18 (Case 4)—Left, Calot jacket, right, after operation

complain of any pain at the present time. She entered the hospital for an operation for deformity (Wyant).

*Examination*—October 2. The patient had been under treatment in the outpatient department since February 10. She had originally a sharp curve to the right in the dorsal region, extending from the second to the twelfth dorsal vertebra with apex at the eighth dorsal. There was marked wedging of the vertebrae and narrowing of the ribs. The patient wore corrective jackets until August, with slight improvement. The curve was so high and so sharp that further corrective treatment promised little if any benefit, and a

straight jacket was applied. The patient's family was to return to Italy in the course of the next year, where treatment would almost surely be abandoned. For this reason, they have determined to submit to an operation.

Measurements were: waist, 25 inches (62.5 cm), chest, below breasts, 28 inches (70 cm), height, in bare feet, 65 $\frac{1}{4}$  inches (164 cm).

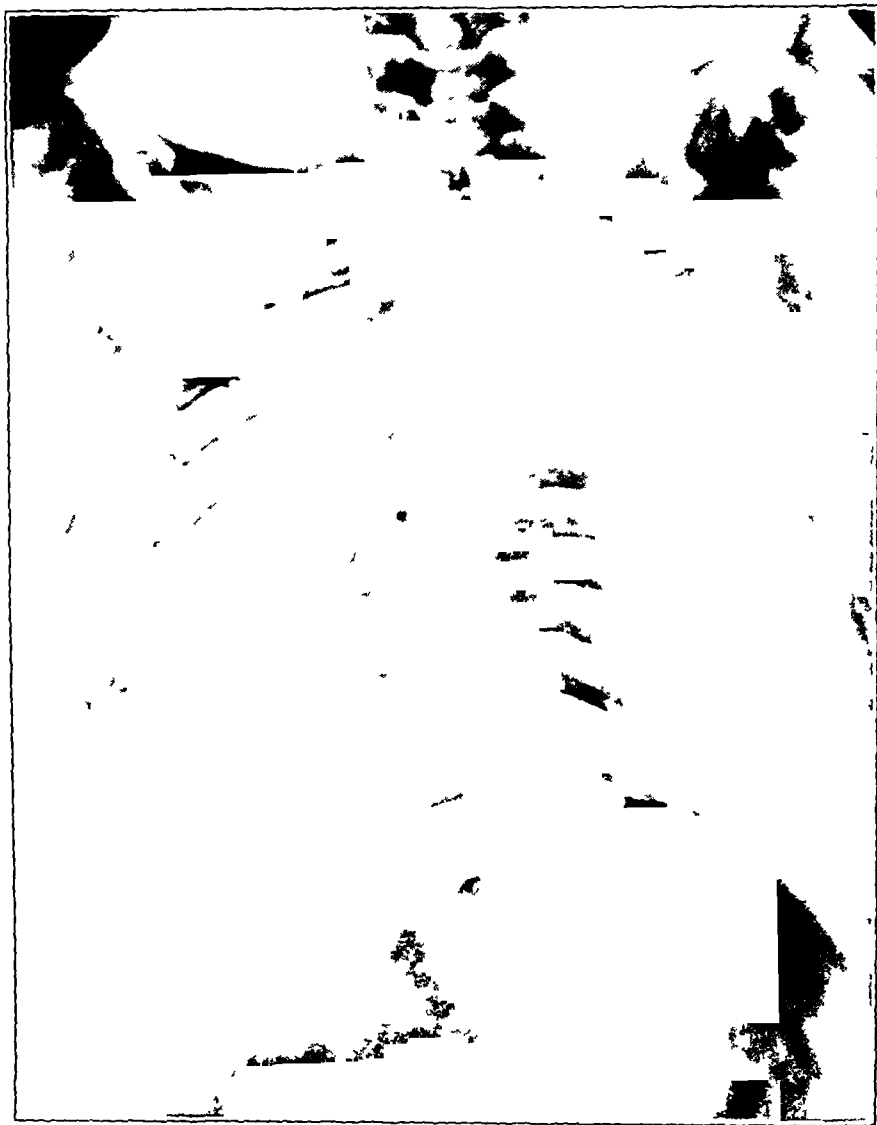


Fig. 19 (Case 4) —Before operation

October 4. The patient was placed on a frame, with traction of 20 pounds (9 kg) on the feet and 8 pounds (3.6 kg) on the head.

October 9. The deformity was slightly improved.

*Operation*—October 22. An incision was made over the spinous processes from the second dorsal to the first lumbar vertebra. The tissue over each spinous process was then incised. The periosteum was divided over the tip and stripped downward. This was accompanied by very little bleeding. Over-

lapped sutures were then taken about one-half inch (13 mm) lateral to the spinous processes, all the way down on either side to prevent hemorrhage during the subsequent procedure. The interspinous ligament was then divided, the tissues and periosteum stripped away from the transverse processes and laminae. The articular processes were curetted. With a V-shaped carving chisel, small slices of bone were removed from the laminae and arranged to interdigitate with the one above as accurately as possible. The spinous process was then half fractured at its base and bent downward so that the tip articulated

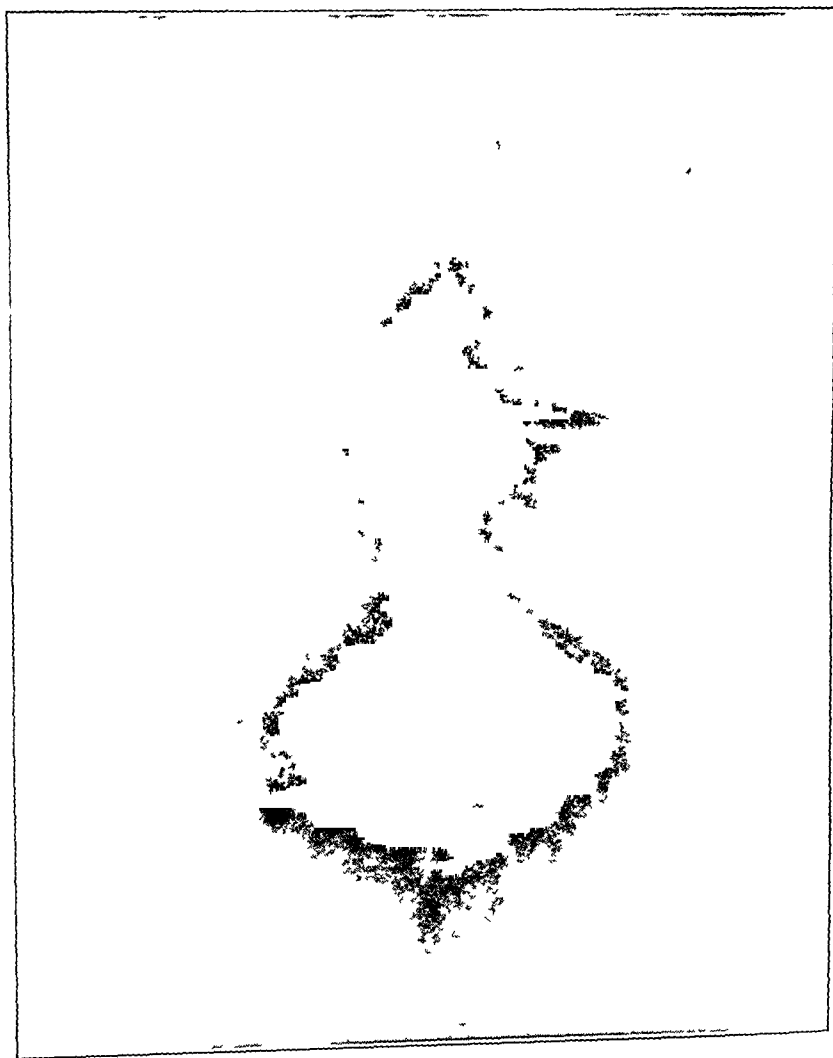


Fig 20 (Case 4) —After operation

with the fractured processes of the vertebra below. This procedure was carried out from the second dorsal to the first lumbar vertebra. The rotation of the vertebrae was comparatively slight. The ligatures were practically entirely effective until the bones were incised. The muscular and ligamentous tissues were united with interrupted kangaroo sutures, the superficial tissues with plain gut, and the skin with No 0 plain gut. Alcohol dressing, sheet wadding and bandage were applied, and the patient was replaced on the stretcher frame. The time required for operation was one hour and three-quarters.

October 28 For five days following the operation, the patient suffered a great deal of pain and discomfort, particularly in the back, and pain on attempts to raise the arms. Following free action of castor oil (October 27), she felt much better and requested the immediate application of the plaster jacket.

November 8 The patient was brought to the plaster room and the dressing was removed. The wound had united by first intention, but there was a small area of necrosis of the skin in the lower portion, apparently from pressure. This was dressed and the patient turned on her face for twelve hours out of twenty-four, the traction in the meantime being kept up.

November 9 The area above mentioned was much decreased in size. A Calot jacket was applied with a window cut out to allow for dressing the wound. A roentgenogram taken after the application of the plaster revealed little if any change either in regard to improvement of the curve or of new bone formation.

November 15 The patient was discharged, in good condition, to return at stated intervals for observation. She was wearing a Calot jacket.

*Readmission*—Feb 8, 1921 The patient had been reporting for observation. She had had no pain or discomfort. She returned to have the jacket removed. While in the hospital, the patient developed influenzal pneumonia.

March 1 The mother insisted on removing the child from the hospital. She was discharged, leaving the hospital against my advice and the advice of others, with a temperature of 103 F.

*Outcome*—April 2 The patient had been at home ill with pneumonia. Her general condition was very poor. Forward bending of the spine seemed to be almost entirely restricted, as was shown in tracing. There was, however, undoubtedly some motion of the lower portion of the area of operation. The patient and family expressed themselves as much pleased, and were quite satisfied with the result so far. The patient was instructed to return for observation.

August 18 With her clothes on, the patient showed no deformity whatever. With the shoulders back, the back appeared flat, although there was considerable protuberance of the ribs on forward bending. The patient was completely satisfied with her appearance. She had been without support since October.

May 1, 1922 The patient's condition continued satisfactory.

*CASE 5—History*—M. L. girl, aged 15 years, entered the outpatient department, Jan 14, 1920, with a clinical diagnosis of rotary lateral curvature of the spine, of about one year's duration. She had had the diseases of childhood. The family history was negative. The patient had always been well. About one year previously the parents observed that the right scapula was more prominent than the left. She was taken to Dr. Lessea, who advised a visit to the Hospital for Ruptured and Crippled. The patient was brought to the outpatient department where she was given a jacket, which she had had changed every two months. She had never had any pain or inconvenience from the jacket. She entered the hospital for correction of the deformity and operation. When examined April 17, 1920, the patient was in good condition, though of rather pale, pasty complexion. She stood in the usual slouchy attitude, chest flat and head forward. She presented a rotary lateral curvature of the spine to the right in the dorsal region, with a slight compensatory curve in the lumbar region. The major curve extended from the third to the eighth dorsal vertebra. There was well marked rotation of the ribs, causing a prominence of the right scapula visible through the clothing. The curvature was fixed. A corrective jacket was applied.

*Comment*—January 20 Since the last two jackets, no further correction of the primary curve had been obtained, all the change taking place above and below and causing exaggerated elevation of the shoulder, which seemed useless and unnecessarily disfiguring. The effect of corrective treatment having thus come to a standstill, operation was determined on, to maintain the correction already gained and to enable the patient sooner to dispense with the apparatus. On removal of the jacket, with the patient lying on her face, there was evident a slight curve to the right in the dorsal region, with a very slight prominence of the ribs. The general aspect of the trunk was symmetrical.

*Operation*—Jan 20, 1921 A 7-inch (17.5 cm) incision was made in the mid-line directly over the spinous processes. Typical Hibbs procedure as described in previous similar operations was carried out from the third to the twelfth dorsal vertebra. The exposure was very satisfactory so that the technic could

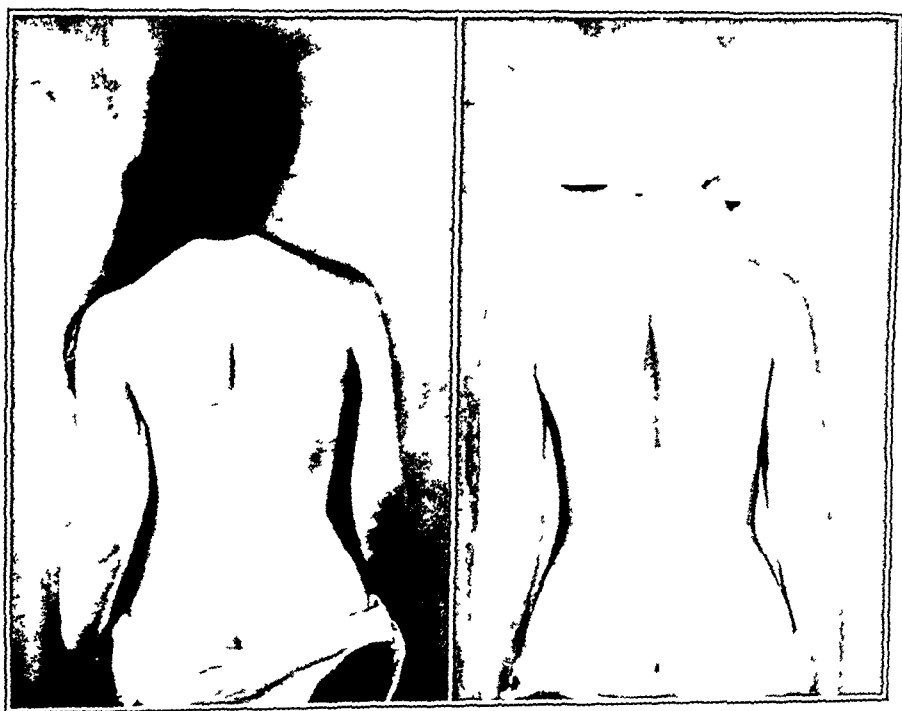


Fig 21 (Case 5)—Left, before operation, right, after operation

be minutely followed. The vertebrae at the center of the deformity were found rotated through an arc of about 45 degrees. There was very little structural change affecting the width of the laminae. The time of the operation was about one and a half hours. The patient's condition was satisfactory.

*After-Treatment*—When the patient returned from the operating room, an electric heater was placed below the frame and the frame and bed were draped with blankets. She had considerable pain requiring about one-fourth grain (0.0162 gm) of morphin toward morning.

January 21 The patient was pale, with eyes widely dilated. She complained of severe pain in the back and did not wish to move the arms.

January 22 The general condition was satisfactory.

January 25 (Dr Klenberg) The patient was improving and felt much better. The temperature was practically normal. The pain in the back was very slight. The patient could talk barely above a whisper.

JANUARY 26 (Dr Nicolì) The throat was congested, the larynx normal except for slight congestion of the cords. There had been recent bleeding from the right nasal passages. Physiologic solution of sodium chlorid warm was used to cleanse the nose, three times a day.

FEBRUARY 5 The patient was turned on the face and the dressings removed. The wound had closed by first intention. Two or three bleeding points caused

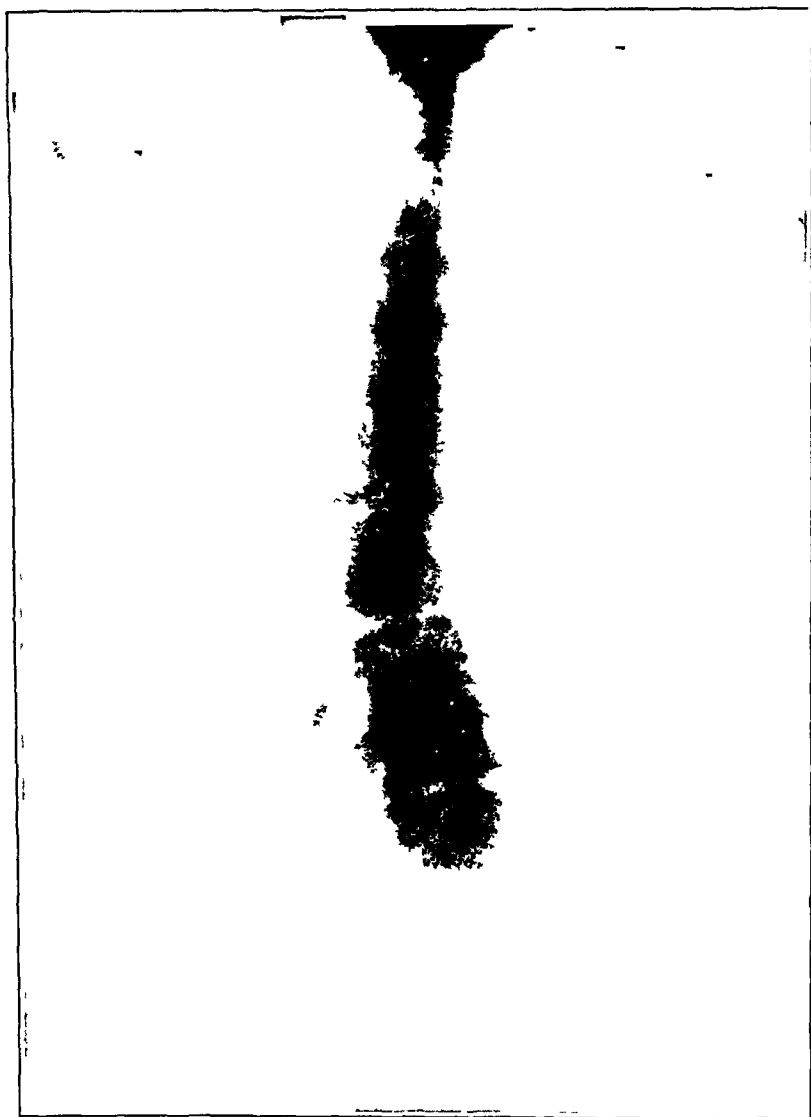


Fig 22 (Case 5) —Before operation

removal of the adhesive plaster, but the skin as a whole was very much irritated. The skin was cleansed with benzín, powdered, and dry dressings applied. Weights attached to the pelvic band (February 4) were increased to 20 pounds (9 kg).

FEBRUARY 27 The patient was comfortable. The temperature had continued normal for four weeks. There was 10 pounds (4.5 kg) traction on the head and 20 pounds (9 kg) on the pelvis (Dr Bost).



March 5 The back was apparently very much flattened since the operation. There was apparently comparatively firm ankylosis of the vertebrae operated on, resisting all movements.

March 19 The spine was apparently fixed throughout the area of operation. The patient was discharged, to return for observation. A photograph was taken.

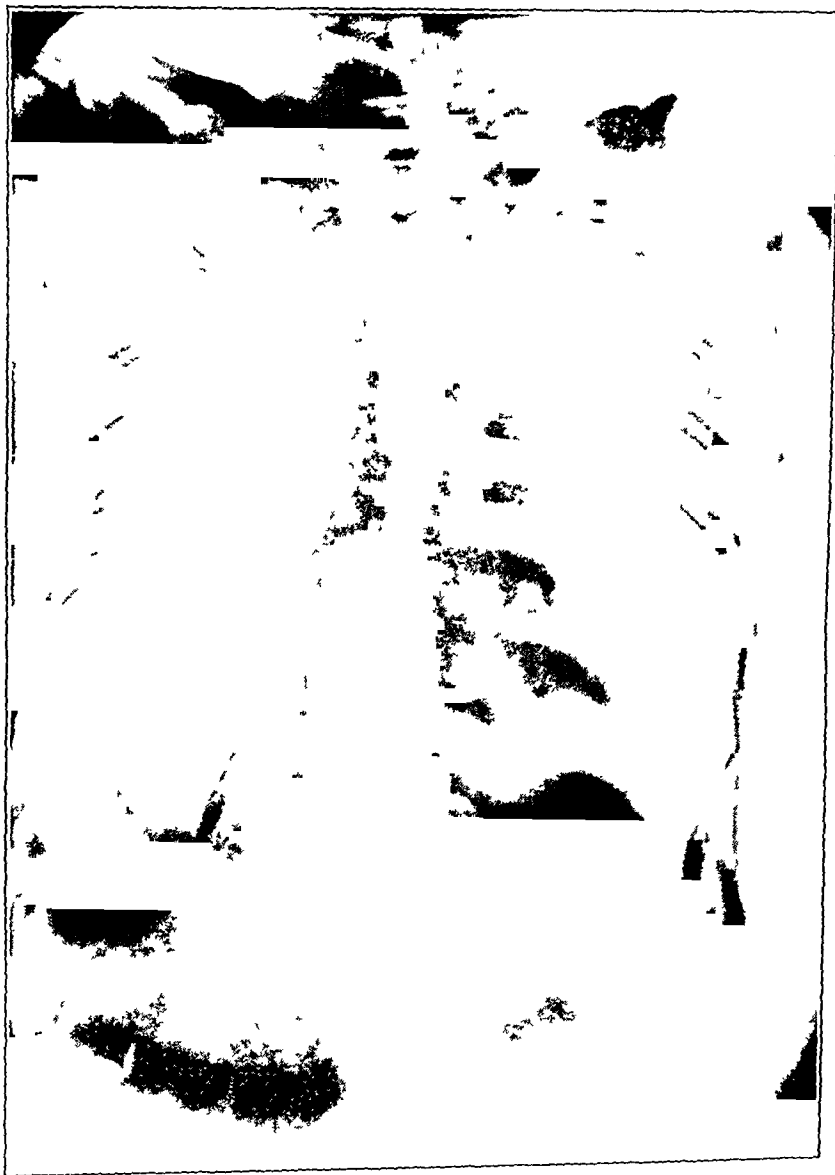


Fig 23 (Fig 5) —After operation

April 16 The patient's habitual posture was very bad. She made no attempt to stand straight. A roentgenogram was made.

May 2 The patient was wearing a corset, which was approved. She was still unable to stand straight. She was instructed to return in two weeks.

June 21 The external appearance was unchanged. The patient was satisfied with her condition, and did not think it was progressing. The roentgenogram

as compared with that taken April 19 revealed a very distinct increase in density in the area of operation. There was no progress of the curve.

July 23. The outcome of the operation itself appeared satisfactory. The patient's posture was as execrable as ever. She was kept on the frame because the irritated condition of the skin made it inadvisable to apply a jacket. It appeared, however, that the spine had stiffened much more rapidly on the frame than in the cases in which the patients were placed in plaster.

May 15, 1922. The patient's general posture was, possibly, slightly improved. There was no change in the spine.

CASE 6—*History*—A P. girl, aged 17 years, entered the outpatient department Jan. 6, 1920, with a clinical diagnosis of rotary lateral curvature of the



Fig. 24 (Case 6)—Left, before operation, right, after operation.

spine. She had had measles at the age of 3 years. Her father, aged 45, mother 42, two brothers and one sister were living and well. There was no history of tuberculosis, cancer, nephritis or diabetes. The chief complaint was spinal curvature, of two years' duration. The patient complained of a weak back, from which she had suffered for one year. It was gradually becoming worse. She had round shoulders and tired readily.

*Examination*—At the present time, the patient had no pain. She had not been ill at the onset. As she stood, the shoulders were approximately level. Prominence of the tip of the scapulae was noticeable on both sides. There was rotary lateral curvature of the spine to the right in the dorsal and slightly to the left in the lumbar region, and considerable rotation of the ribs. The deformity was rigid.

November 9 Plaster jackets had been applied at two-month intervals. A roentgenogram taken September 2 showed a marked overcorrection at the upper and lower extremities of the spine, the original middle curve being almost, but not quite, corrected. As the overcorrection in the upper dorsal region was somewhat undesirable and entirely due to the elevation of the shoulder, the jacket applied October 30 did not include the shoulder. The roentgenogram

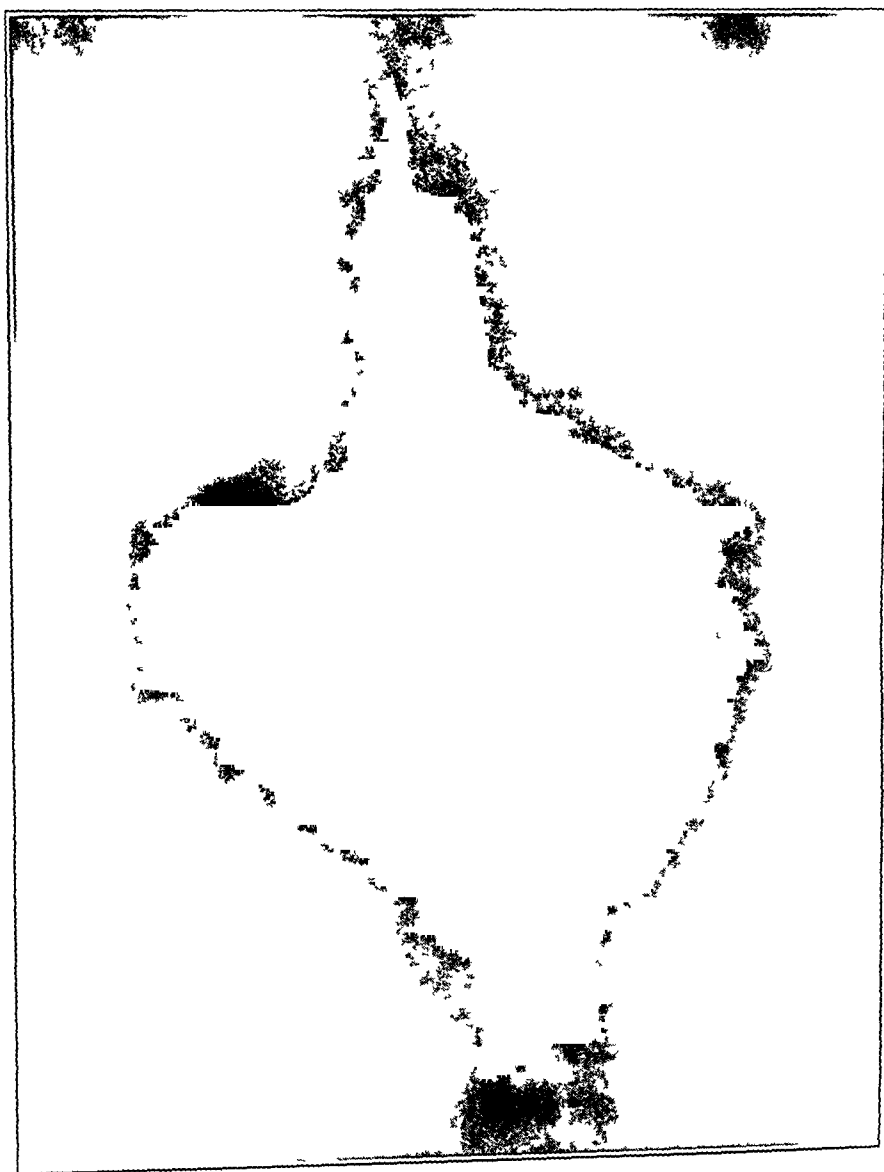


Fig. 25 (Case 6) —Before operation

showed the spine in slightly better position than with the former jacket. Externally the trunk appeared symmetrical although the original dorsal curve was not entirely corrected.

*Readmission*—April 24, 1921. The patient reentered the hospital.

*Operation*—April 25 (Dr. A. Whitman, assistants, Drs. Bost and Wyant). A Hibbs operation was performed from the third to the eleventh dorsal vertebra. The usual technic was varied by splitting the spinous processes transversely

and vertically, and spreading the four parts upward and downward overlapping as much as possible with the fragments of the one below. The attachment of the spinous processes to the vertebral arch was not broken. The tissues were closed with interrupted kangaroo, and No. 1 plain gut for the skin.

There was slight lateral deviation of the spine, but not more than 20 degrees rotation.

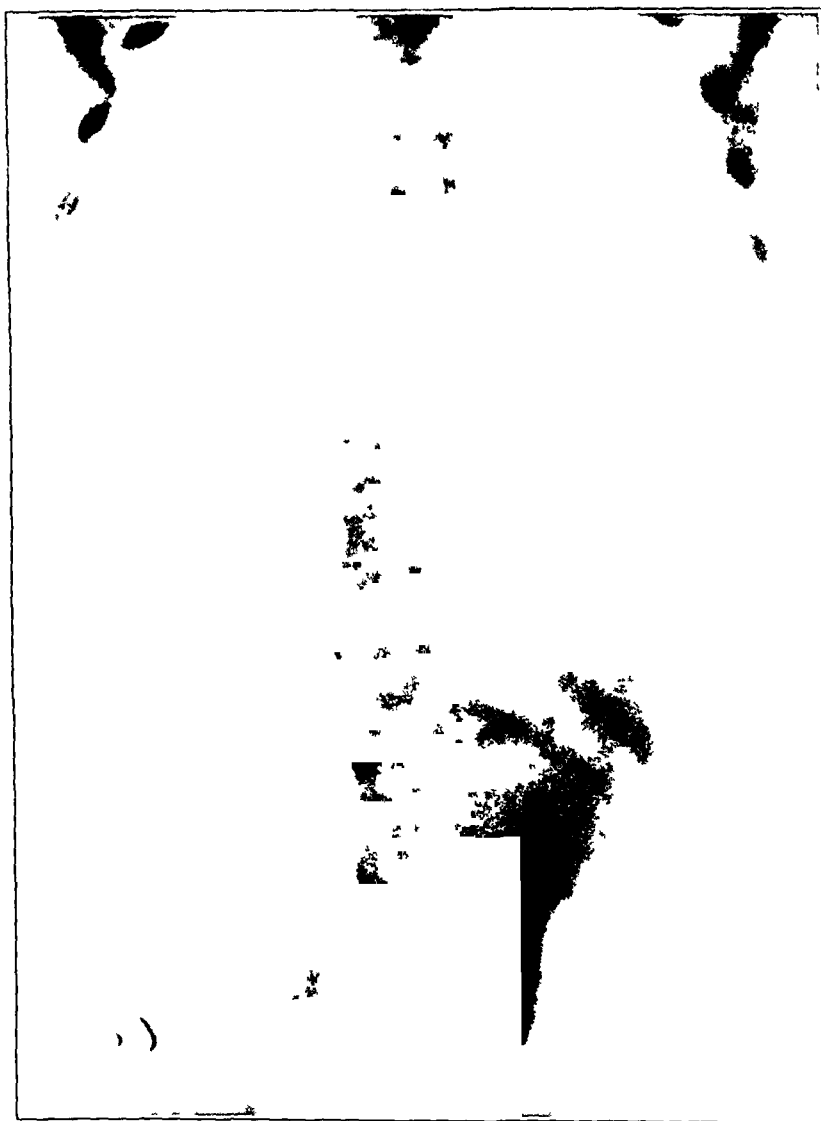


Fig. 26 (Case 6) —After operation

*Outcome*—April 26 The patient had had very little pain following the operation. She now complained of precordial distress.

April 28 The patient was comfortable. Traction was applied.

May 5 The wound was closed by first intention. There was slight redness over the lower end of the scar, and it was also somewhat tender to pressure. The back was clean.

June 12 Beginning June 1, the patient had turned on the face, and voluntarily extended the spine ten times each day, for the purpose of producing exuberant callus in the area of operation. The motion had caused her no pain.

June 18 The area of operation appeared stiff, and a low plaster jacket was applied for the purpose of steadying the lumbar region during the process of muscular recovery.

June 20 The patient was discharged, wearing the plaster jacket, to return for observation (Dr Wyant).

August 21 The jacket was removed. The patient was cautioned to lie down at frequent intervals, and warned that she would have pain and weakness in the back.

August 28 The patient complained of severe pain in the back and a continual tired feeling.

September 1 The pain in the back had been completely relieved by the application of an ordinary corset.

October 22 The patient had been wearing a corset since the last report. She took no interest in the maintenance of a proper posture and walked about everywhere with the typical fashionable droop. In spite of this, the deformity of the spine had not progressed, and the external appearance was satisfactory.

April 22, 1922 The patient continued to affect the debutante slouch and habitually carried the left shoulder high. There was, however, apparently no change in the spine.

CASE 7—*History*—E. A., woman, aged 19, a milliner, entered the outpatient department, May 16, 1920, with a clinical diagnosis of rotary lateral curvature of the spine. She had had measles at 10 years. Her father, aged 52, mother, 48, one brother and two sisters were living and well. Two brothers died in infancy. Her chief complaint was curvature of the spine, of thirteen months' duration. She had been well until thirteen months previously. At that time, she began to have pain in the right shoulder and arm, and she noticed that her right shoulder was higher than her left. This continued for one month. She came to the outpatient department, May 23, 1920. A plaster-of-Paris jacket was applied and she had had a new one put on every two months since (Dr Robert E. Burns).

May 17 After the treatment of the past year, the spine seemed practically corrected. The patient was admitted to the hospital for operation to maintain the correction.

*Examination*—The patient was in good condition. Externally, the trunk was somewhat asymmetrical, as is shown in the tracing. There was marked flattening of the ribs on the right side from the pressure of the jacket. The spine was apparently straight. There were very evident flexion and extension taking place in the dorsal spine as was shown in the tracing taken with the patient prone on the frame, and when she lifted herself in the air. The first roentgenogram taken through the plaster, May 27, 1920, showed a slight curve to the right in the dorsal region. The roentgenogram taken through the plaster, Feb. 24, 1921, showed the spine practically straight.

*Operation*—May 17, 1921 (Dr A. Whitman, assistants, Dr Bost, Dr Wyant and Dr Burns). The usual Hibbs operation was performed from the second to the eleventh dorsal vertebra. Considerable rotation of the vertebrae was present more than would have been supposed from the roentgen-ray or physical examination. The exposure was unusually good, and the procedure very thorough. The usual technic was varied by splitting the spinous processes vertically and

again horizontally, and then spreading the fragments in the four directions. This appeared to give unusually good bony contact. The time of operation was one hour and twenty minutes. The pleura on the left side was penetrated by an artery clamp in the hands of an assistant. The perforation was immediately closed by allowing the muscle to fall over it.

*Outcome*—May 22 The chest was examined anteriorly. It was resonant, and there was vesicular breathing. No friction rub was felt or heard. There were no rales (Collens).

May 24 The patient's convalescence had been uneventful, except that she had complained of occasional pain. The dressings were removed. The wound was closed by first intention. There were signs of pressure at the lower extremity of the wound.

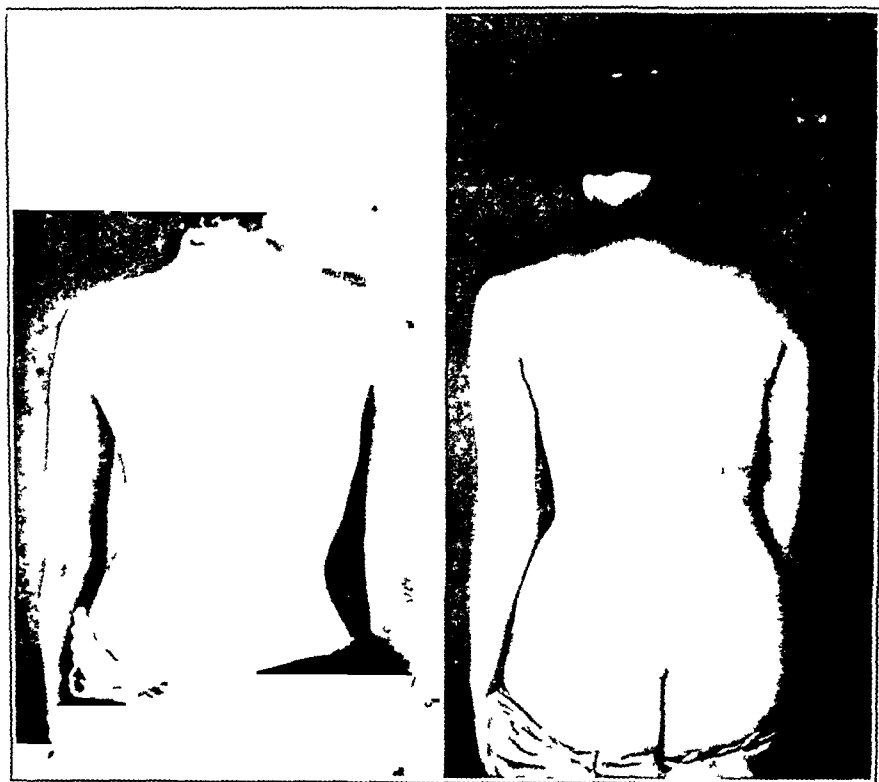


Fig 27 (Case 7)—Left, before operation, right, after operation

June 24 A roentgen-ray examination of the spine throughout the area of operation revealed an apparent complete fusion, in that the intervertebral spaces were scarcely visible.

June 26 A confirmatory roentgen-ray examination failed to reveal any fusion whatever.

July 13 The spine appeared stiff in the area of operation. A low plaster jacket holding the lumbar region in position was applied. A roentgenogram of the region of operation was taken.

July 15 A roentgenogram showed no change. The patient was discharged, wearing a plaster jacket, to return for observation.

August 9 The patient was comfortable. The jacket was in good condition. There was no alteration in the external aspect of the trunk.

September 27 The patient was now wearing an ordinary corset and suffered occasional weakness and discomfort in the lumbar region, and in the arms. She felt, however, that she was steadily improving. The external appearance of the trunk was symmetrical. There was apparently, complete rigidity of the area of operation.

May 1, 1922 The patient's general and local condition was excellent.

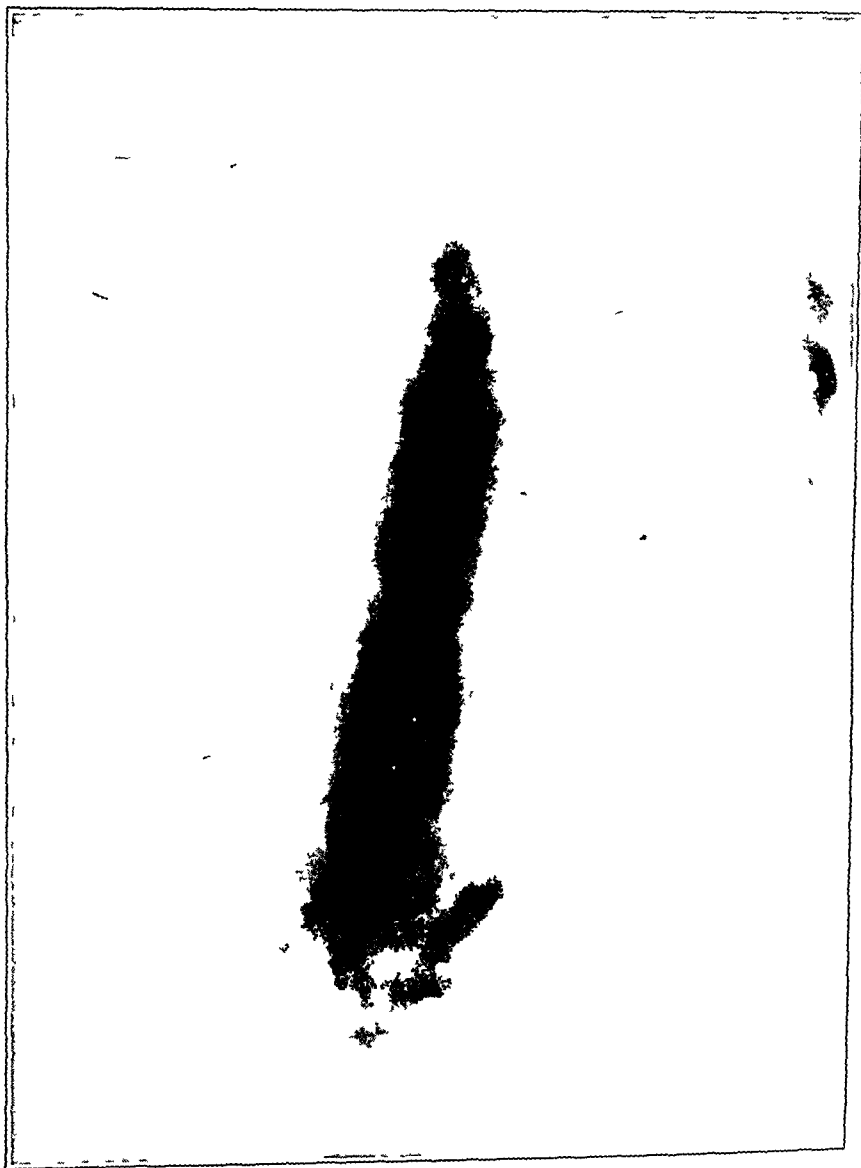


Fig 28 (Case 7)—After operation

CASE 8—*History*—M C, girl, aged 16 years, was admitted to the outpatient department with a clinical diagnosis of rotary lateral curvature of the spine. She had had measles and whooping cough at 2 years. Her father, aged 45, mother, 44, one brother and two sisters were living and well. One brother died of pneumonia at 27 months, and one sister, of spinal meningitis at 3 months. The chief complaint was curvature of the spine, of two years' duration.

duration Two years previously, the patient's mother noticed that she had a spinal curvature Nothing was done about it for one year The trouble became worse during the interval and, April 15 1920, she presented herself at the hospital for treatment She was put in a cast Except for changes every two months, she had worn it continuously since Every two months, she had had a roentgenogram taken at the time the cast was changed The condition had improved, but in order to prevent a recurrence, she entered the hospital to have an operation to fix—"stiffen"—the spine When examined April 13, 1920, the patient was in fair condition She presented a rotary lateral curvature of the spine to the right in the dorsal region There was extreme prominence of the

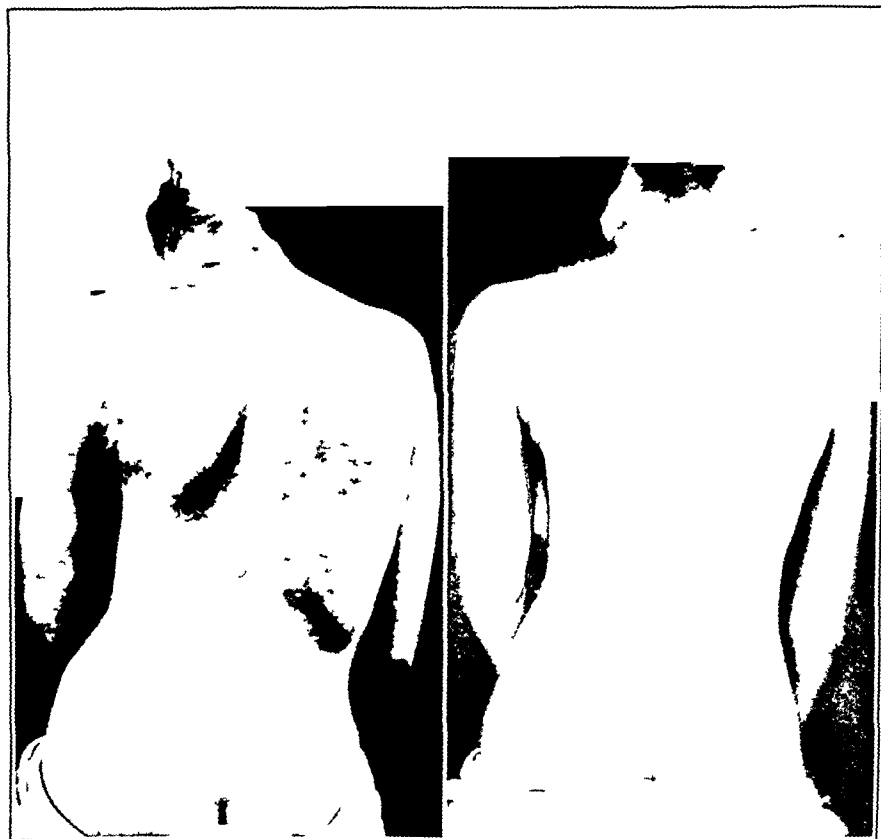


Fig 29 (Case 8) —Left, before operation, right, after operation

ribs on the right side, amounting to razor back deformity, with corresponding concavity of the ribs on the left The spine apparently was completely rigid A roentgen-ray examination was made and photograph taken

April 2, 1921 No improvement was made between the application of the last and next to the last jacket The patient was therefore admitted for treatment on a frame with traction, as a preliminary to operation The external appearance of the trunk was one of almost complete symmetry There was still slight prominence of the lower ribs on the right side There was a slight curvature palpable to the right in the dorsal region

*Operation*—April 6 (Dr A Whitman) The usual Hibbs operation was performed, from the second to the twelfth dorsal vertebra The bleeding was



entirely controlled by packing. No ligatures were tied. There was very slight lateral deviation of the spine, but considerable rotation, to about 25 degrees. The experiment was tried of correcting the rotation by pressure on the spinous processes, which proved quite impossible. One could barely move the vertebra, which immediately returned to its original position. The ligamentum nuchae



Fig. 30 (Case 8) —Before operation

was sutured with kangaroo, the subcutaneous tissues sutured with plain gut, the skin with 0 plain gut.

The patient had a copious bowel movement during the operation which was noted, in case infection might develop.

*After-Treatment*—April 19. On account of the irregular temperature and the blood count, the patient was dressed on the eighth day. The wound was completely healed, and there was no sign of superficial infection. The con-

alescence, except for the variations in temperature, had been extraordinarily smooth. The patient had not complained of pain since the first twenty-four hours. All dressings were removed. Traction was reapplied on the fourth day. The patient now had 20 pounds (9 kg) traction on the waist and 5 pounds (2.3 kg) on the head. The appearance of the back was satisfactory.

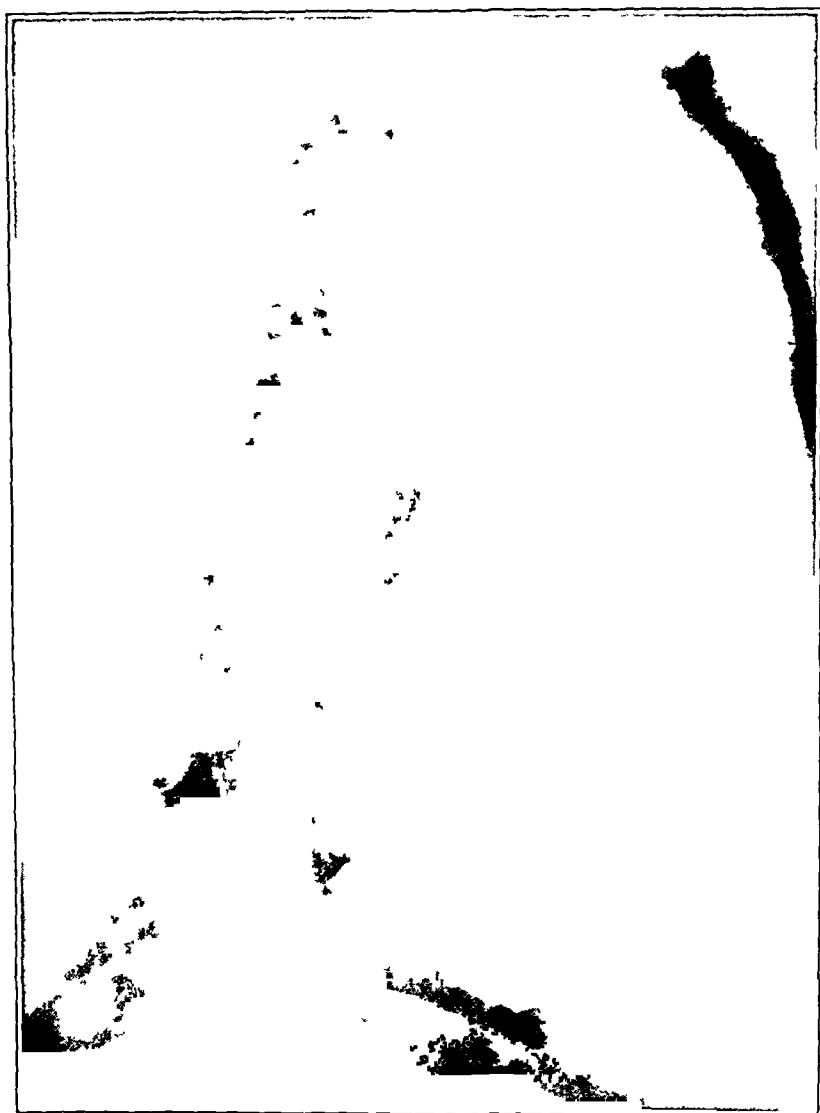


Fig 31 (Case 8) —After operation

April 28 The patient was turned on the face and there seemed to be some lateral fixation.

May 17 The patient was removed from the frame and was taken to the plaster room to have a corset applied. She was to return for another week on the frame, but she preferred a jacket to a corset. On this account, she was allowed to sit up (May 19).

*Outcome* —(Dr Bost) May 20, she was discharged, improved.

July 21 The spine was apparently stiff The patient was satisfied that the deformity had not progressed She wished to wear the plaster through the summer A roentgenogram was taken

October 20 The patient had worn a plaster corset at her own request throughout the summer It was now removed and an ordinary whalebone corset substituted The patient was instructed to return to the gymnasium at regular intervals for exercises There was great atrophy of the lumbar muscles, but apparently no increase in deformity

December 28 There was still considerable atrophy of the lumbar muscles Exercises were advisable, but apparently impossible There had been no change in the deformity of the spine

May 18, 1922 The patient had been taking exercises The general condition and appearance were excellent

CASE 9—*History*—L. S., boy, aged 12 years, entered the outpatient department, Dec 11, 1919, with a clinical diagnosis of lateral curvature of the spine

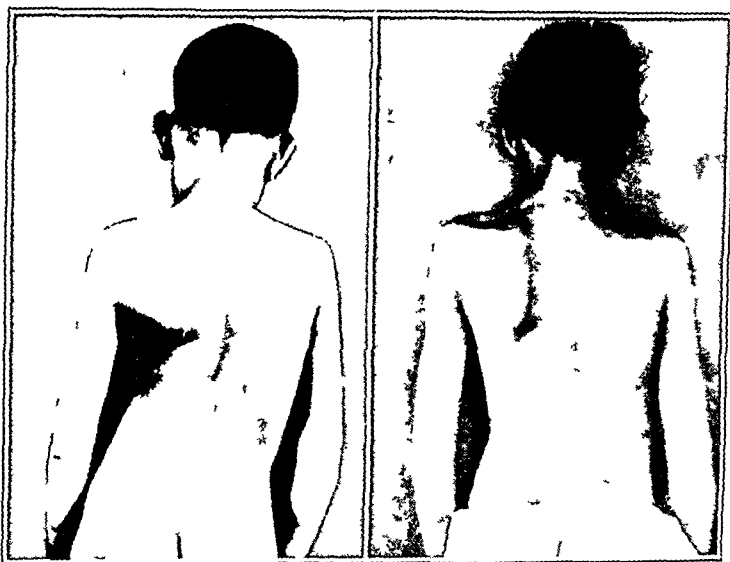


Fig 32 (Case 9)—Left, before operation right, after operation

He had had whooping cough when 2 months old, measles at 4 years, and typhoid fever at 6 He was very sick with typhoid fever for three months Following this, he had hemorrhages, which subsided after the removal of his tonsils The family history was negative The chief complaint was curvature of the spine, of 1 year and 8 months' duration Two years previously (October 1917), the patient had fallen from a horse, landing on the cement floor of a barn, breaking the left forearm It was following this that the curvature of the spine was noticed Aside from massage and manipulation, nothing had been done to correct this condition (V. W. Purdy)

*Examination*—December 13 (Dr. Whitman) The boy was in good condition He stood with the trunk displaced toward the right side, and the left pelvis very prominent There was marked fixed general rotary, lateral curvature, involving the entire dorsal region up to about the sixth vertebra There was marked deformity of the ribs and a fair degree of flexibility

December 13 A corrective jacket was applied

December 16 (Dr Klemberg) A roentgenogram taken Dec 13, 1919, following the application of a corrective jacket, showed very marked reduction of the dorsal curve

*Readmission*—March 16, 1920 The patient had been ill since leaving the hospital, for about one week, five weeks before The physician said that he had purpura hemorrhagica Nothing had been done for his orthopedic condition

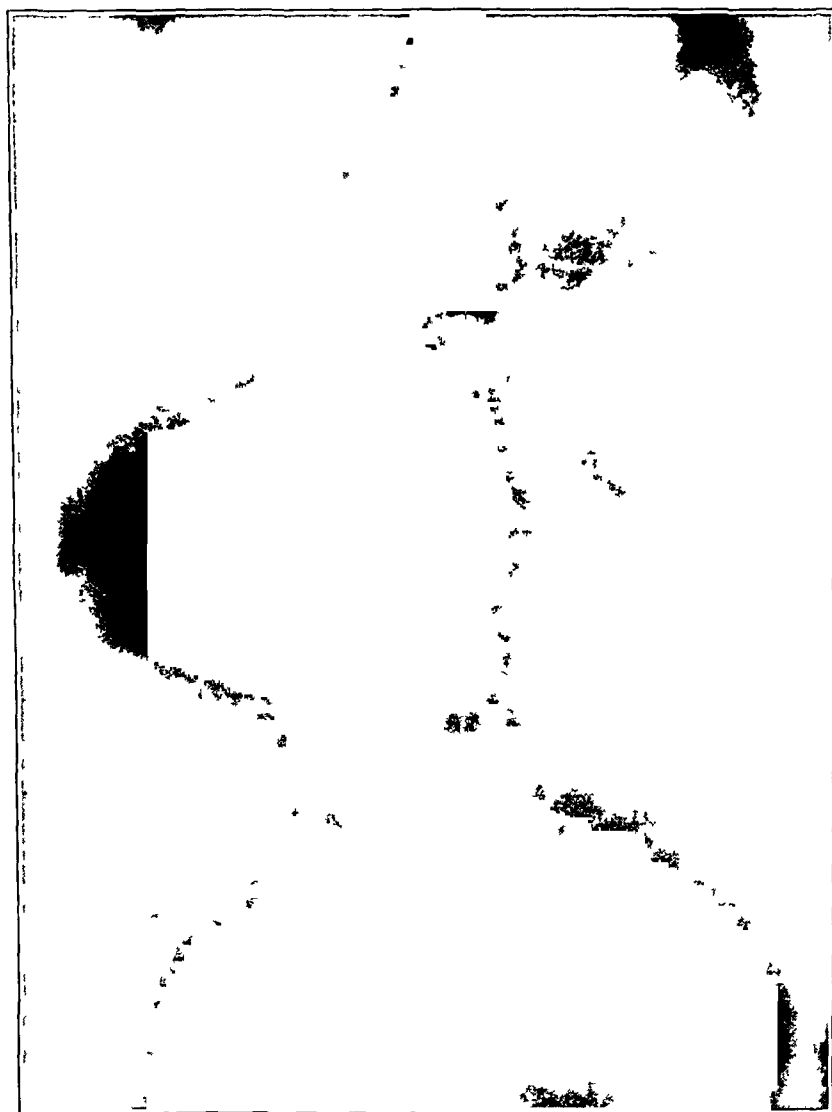


Fig 33 (Case 9) —Before operation

since his discharge The old plaster was now removed and replaced with a new one (B L Schoolfield)

March 17 The patient was discharged wearing the plaster jacket (B W Moffat)

*Comment*—April 2 The last jacket, applied four months ago, did not include the right shoulder, as there appeared to be too much exaggeration of the curve

above the original deformity. A corrective jacket was applied elevating the left shoulder and depressing the right. On removal of the last jacket, there was no apparent curvature of the spine. There was very slight prominence of the ribs on the right side, and a mild curvature to the right extending from the fourth to the twelfth dorsal vertebra. The external appearance of the trunk was excellent.

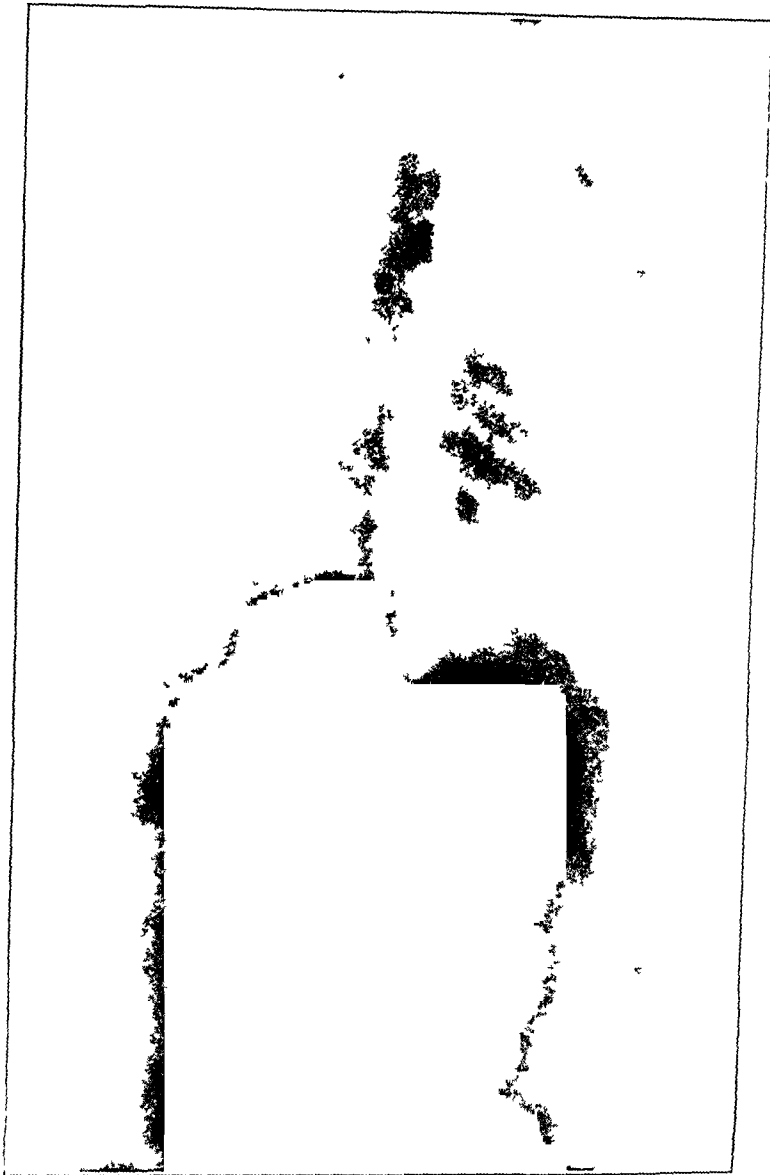


Fig 34 (Case 9) —After operation

*Second Readmission*—July 12 (Dr Whitman) Since the last report, the boy had been under continuous treatment by jackets. He now returned for operation. The extreme deformity of the spine was almost corrected, as shown by the tracings.

*Operation*—July 20, 1921 (Dr A. Whitman, assistant, Dr Wyant) A fusion operation extending from the third dorsal through the first lumbar vertebra was

performed The exposure was unusually good, and for the first time I felt certain that I had destroyed the articulations between the vertebrae The spinous processes were split in four parts vertically and horizontally, two were turned up, and two down, so that the interdigitation was very satisfactory The ligaments were sutured with kangaroo and chromic gut The skin was closed with catgut An alcohol dressing was applied The time of operation was one hour

*After-Treatment and Outcome*—July 26 The dressing was changed, the wound was clean, a dry dressing was applied (R E Burns)

July 30 (Dr Whitman) After the operation, the patient complained of pain in the left shoulder Many of these patients complained of pain in the shoulder, although the line of incision was not opposite the shoulder

August 4 The patient was very comfortable, except for occasional pains in the left shoulder which were not very severe (Dr Sneed)

The wound was dressed It was entirely healed (R E Burns)

September 3 The spine was stiffening The external deformity of the ribs was somewhat improved

September 15 The wound was entirely healed The patient was removed from the frame and a plaster jacket applied, shoulders not included (Dr Wyant)

The patient was discharged wearing a low plaster jacket to support the lumbar region

November 20 The plaster corset was removed and a canvas reinforced corset reapplied There was atrophy of the lumbar muscles and some stiffness in the lumbar region Massage and exercises were prescribed

December 20 The patient reported by letter that his improvement continued

April 22, 1922 There was no progress of the deformity The general condition was excellent

CASE 10—*History*—C M, girl, aged 16 years, entered the outpatient department July 22, 1921, with a clinical diagnosis of rotary lateral curvature of the spine Her general health was excellent She had had the usual diseases of childhood Her mother died of pneumonia at the age of 48 The history of the father was unknown There was no history of cancer, tuberculosis or heart disease The chief complaint was curvature of the spine, of two and a half years' duration Nothing unusual was noted about the child until she was 12½ years of age, when an aunt noticed that the right shoulder drooped It was thought that the carrying of school books caused it The child was brought to the hospital and a plaster cast was applied She had worn it constantly for two years, and now came in for operation (Dr Wagner)

*Physical Examination*—The child was in fair condition, very pale, flat chested and evidently considerably under weight She presented a well marked rotary, lateral curvature of the spine to the right in the dorsal region, with a slight compensatory curve to the left in the lumbar region The right shoulder was high, the left hip prominent There was considerable rotation of the ribs, and prominence of the scapulae A roentgenogram and photograph were taken, and corrective jackets prescribed

Since July, 1919, the patient had been under treatment in the outpatient department, corrective jackets being applied at intervals of two months She had, apparently, now reached the maximum correction and was sent to the hospital for operation

*Operation*—July 26, 1921 (Dr A Whitman, assistant, Dr Wyant) The fusion operation was performed from the third dorsal to the twelfth dorsal vertebra There was very slight rotation of the spine and no lateral deviation The

spinous processes were split horizontally and vertically, and then pried upward and downward, giving a very satisfactory interdigitation. It was also thought that the intervertebral articulations were effectually curetted. The ligaments were sutured with chromic gut, the subcutaneous tissues with plain gut, the skin with horse-hair. The time of operation was one and one-half hours.

*Outcome*—July 28. There was bleeding through the dressing the night following the operation. The general condition was excellent. The patient suffered very little pain.

August 2. The wound was clean. The stitches were removed and dry dressing applied.



Fig. 35 (Case 10)—After operation

August 23. A roentgenogram showed for the first time, in the series of cases, apparent destruction of the articular processes.

September 3. The external appearance of the patient's back was satisfactory and there was evident beginning stiffness in the operative area.

September 24. The patient was removed from the frame and a plaster jacket applied.

September 26. The patient was discharged wearing a plaster-of-Paris jacket, to return for observation in one week (Dr. Wyant).

December 20. The plaster corset was removed and an ordinary reinforced corset substituted. The patient was instructed to take exercises for the lumbar muscles and gradually to discard all apparatus.

April 22, 1922. The condition continued to be satisfactory.

CASE 11—*History*—B K, schoolgirl, aged 12 years, entered the outpatient department, Aug 5, 1920, with a clinical diagnosis of rotary lateral curvature of the spine. Her general health was extremely good. She had had the usual diseases of childhood, no pneumonia nor typhoid. Her mother, aged 59, and father, 50, were alive and well. There was no history of cancer, tuberculosis,

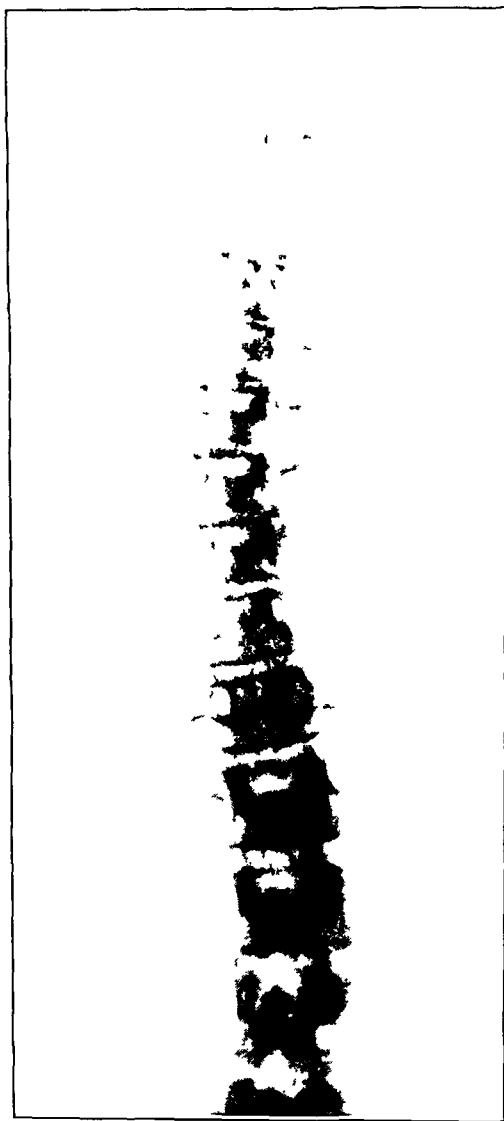


Fig 36 (Case 10) —After operation

or heart disease. The chief complaint was curvature of the spine, of one year's duration. When the child was 11 years old, the mother noticed that the right shoulder and the right side of the back were more prominent than the left. She was sent to the outpatient department and had been treated continuously with plaster jackets. She complained of no pain and came in for operation (Dr Wagner).



*Physical Examination*—The child was in good condition, and stood very erect. She presented a lateral curvature of the spine to the right, a long, single curve extending throughout practically the entire length. The spine was flexible, but the curve could not be entirely corrected. The left hip was exceedingly prominent. There was comparatively slight rotation. The case seemed especially favorable for corrective treatment. A roentgenogram and photograph were taken.

August 3. The corrective jackets had been applied at two-month intervals. According to the roentgenogram, the curvature of the spine was now completely corrected. This correction, however, had been obtained at the cost of considerable flattening of the right chest. The patient entered the hospital for operation to assure the maintenance of the correction.

*Treatment*—August 6. The jacket was retained until the frame could be made (Dr. Wyant).



Fig. 37 (Case 11)—Left, before operation, right, after operation

August 12. The patient was placed on the frame with 5 pounds (23 kg) traction on the head and 10 pounds (46 kg) on each leg, as a preliminary to operation.

*Operation*—Aug. 16, 1921. The operation extended from the third to the twelfth dorsal vertebra. There was no lateral deformity but there was about 45 degrees of rotation in the middorsal region, with corresponding distortion of the laminae and transverse processes. The usual technic was carried out with thoroughness, great attention being paid to the attempt at destruction of the articular processes. The spinous processes were split horizontally and vertically, and turned upward and downward, interdigitating in a very satisfactory manner. The ligaments were closed with chromic gut, the subcutaneous tissue with plain gut, and the skin with horse-hair. The time of operation was one hour and ten minutes.

August 19 The patient recovered from the operation very satisfactorily. She was now on a convex frame continuously but no traction was applied as yet. She complained of very little pain.

August 21 The wound was in excellent condition. There was no swelling or redness, and no tender areas. There was a slight rise in temperature, but no discomfort (Dr L. Wagner).

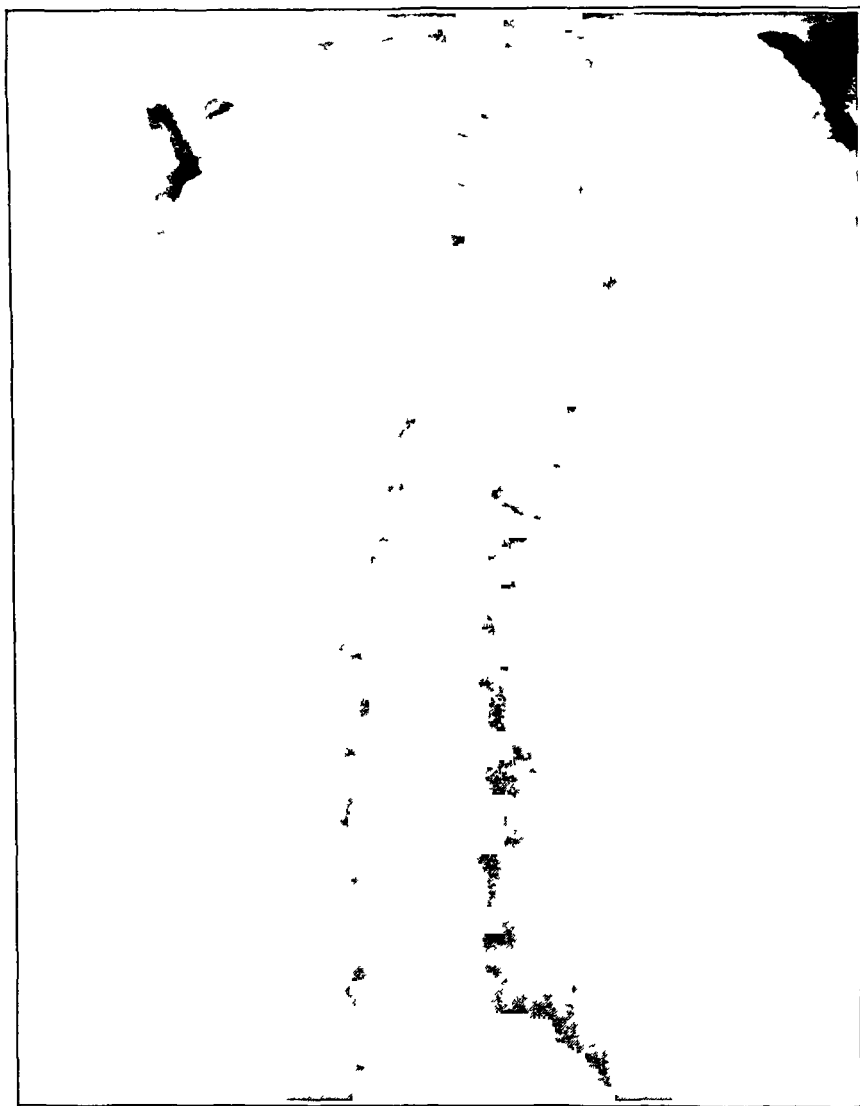


Fig 38 (Case 11) —After operation

August 25 The dressing was changed and the stitches were removed from both wounds, which had healed by first intention (R. E. Burns).

September 3 On the patient's eighth day she was discovered turned on her face, propped on her elbow, conversing with her sister. This fact is noted as indicative of lack of postoperative pain.

September 9 The weights on each side of the pelvis were increased to 10 pounds (4.6 kg). The weight on the head had also been increased to 10 pounds.

The patient complained of no discomfort. Right angled splints were applied to each foot (Dr Wagner).

October 18. The patient was removed from the convex frame and a low straight plaster jacket was applied. She complained of no discomfort (Dr Wagner).

December 27. The plaster corset was removed and an ordinary corset substituted. The patient was instructed to have massage and exercises for the lumbar muscles. Her general appearance was excellent.

May 1, 1922. The patient's condition has continued to be satisfactory.

#### SUMMARY

1. Given a structural scoliosis of unknown origin in the case of an adolescent who applies for treatment because of progressive deformity, the prognosis as to the arrest of deformity is uncertain.

2. A certain number of such conditions may be held in check by apparatus and exercises, provided the patients at all times take a personal interest in their posture.

3. The only means of improving the actual deformity and the external appearance of the trunk is by apparatus embodying at least some of the principles outlined in the description of the corrective jacket.

4. The maximum degree of improvement having been obtained, the spine must be held corrected for a period of years while accommodative changes in the vertebrae take place.

5. This maintenance of correction can be effected only by a corrective jacket, recumbency, or operation.

6. As a climax to the corrective treatment, and as postoperative fixation, recumbency on the convex stretcher frame has proved effective in still further reducing the deformity of the ribs, and in allowing full opportunity for chest expansion.

7. While the amount of actual anatomic correction of the deformity of the vertebrae is exceedingly doubtful, the improvement in the patients' external appearance seems to have been maintained by the operation. It has also greatly abbreviated the period of their convalescence.

8. The older the patient, the more rapid the ankylosis.

# THE OPERATIVE TREATMENT OF SCOLIOSIS \*

SAMUEL KLEINBERG, M D

NEW YORK

The problem of the complete correction or cure of structural scoliosis is still unsolved. Thus far treatment has been directed toward, and necessarily limited to, reducing the curvature, improving the appearance of the back and maintaining that improvement. There are various methods of treatment whereby improvement may be obtained in a large percentage of cases, but there is no known method which assures permanent results. To make sure that the correction will be lasting, we have been compelled to prolong the treatment over a period of from five to ten years. If a patient, after having undergone corrective treatment for several years, has retained the improvement and has shown no signs of relapse during an additional period of two or three years, we feel warranted in believing that the deformity will not increase. We can, however, at no time feel positive about this, for we all see cases become worse when treatment is interrupted, and sometimes even while corrective treatment is in progress. The deformity may even remain stationary for a number of years and then become more severe. I have seen scoliotic deformity increase during adult life. While, therefore, it is true that some cases remain mild and stationary, with or without treatment, the fact remains that in many patients the deformity does become severe and that in any given instance we are unable to prognosticate the course or state with any assurance that the deformity has reached its greatest development.

Some more certain method must, therefore, be found whereby a given spinal curvature can be fixed, so to speak, so that it will not increase. Such a method might then be applied in the earliest stages of the deformity and the many very severe curvatures of the paralytic, rachitic and razor-back variety might be prevented.

Dr Hibbs,<sup>1</sup> encouraged by the results of his fusion operation in Pott's disease, reasoned that this operation ought to give satisfactory results in scoliosis. He has operated, we are told, in many cases, and believes that fusion of a part of the spine in scoliosis will prevent further increase of deformity. Dr A Mackenzie Forbes<sup>2</sup> also believes that fusion of the vertebrae will arrest the course of the deformity.

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\* Read before the Orthopedic Section of the New York Academy of Medicine, April 21, 1922

1 Hibbs, R A. Treatment of Deformities of the Spine Caused by Poliomyelitis, J A M A 69 787 (Sept) 1917

2 Forbes, A M. J Orthop Surg 2 357 (June) 1920

He uses a somewhat different technic from that employed by Hibbs. The principle, however, is the same. Both Hibbs and Forbes aim to obtain osseous fusion of the posterior arches of a number of vertebrae, usually from eight to twelve, in the belief that a solid spinal column will have less tendency to rotary lateral deformity than a segmented one. Whether this is true, time and experience alone will teach us, but the hypothesis is reasonable and this treatment deserves an extensive trial.

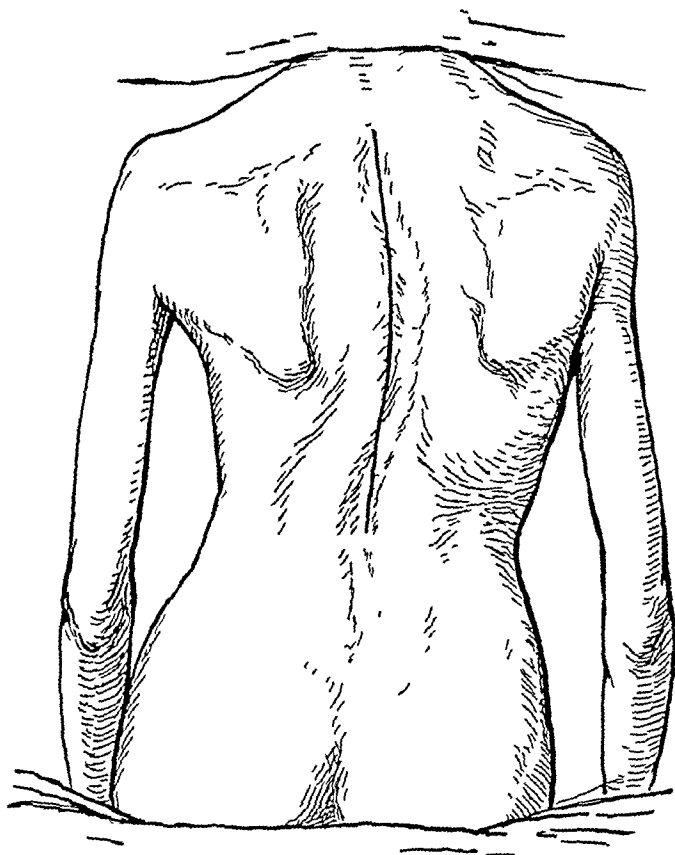


Fig 1—Right dorsal scoliosis, showing line of incision extending from second dorsal vertebra to dorsolumbar junction

Believing that the operative treatment has much to recommend it, and that it may actually afford an opportunity of arresting the progress of scoliotic deformity, I adopted it about two years ago. In my earliest cases I used the Hibbs fusion operation<sup>3</sup>. I found, however, that I did not always obtain complete bony ankylosis. This appeared to be due to the fact that I had operated in very severe cases in which, on account of the extreme deformity of the vertebrae and ribs, it was practically impossible to carry out all of the steps of the Hibbs fusion

<sup>3</sup> Humphries, R. E. The Operative Treatment of Scoliosis, *Tr. Sec. Orthop. Surg., A. M. A.*, 1921, p. 58.

technic I, therefore, decided to supplement the Hibbs fusion by the use of a beef bone graft I chose a heterogenous graft for two reasons First, its use would not prolong the operation as would the removal of a graft from the patient's tibia, second, it could be prepared of the desired length and thickness and with the necessary curve, which may not be possible with the autogenous graft

At the Hospital for Ruptured and Crippled, fusion of the spine in scoliosis forms but a part of a system of treatment which not only is believed to be satisfactory, but which also is likely to displace the older jacket and brace methods This treatment may be divided into the preoperative, operative and postoperative phases

#### PREOPERATIVE TREATMENT

From my experience<sup>4</sup> in the last few years with the use of suspension in the application of corrective jackets, I know that improvement results from fixation of the trunk, with the spine in extension or hyperextension The projection of the ribs is reduced, the deformity becomes less conspicuous, the appearance of the back is improved, and there is an opportunity for proper expansion of the chest It was, therefore, suggested by Dr Royal Whitman<sup>5</sup> that the patient be placed on a frame for a short time so that some improvement might take place before fusion of the spine is undertaken This procedure has proved unusually profitable to the patient, and now forms an exceedingly important part of our treatment It has gradually been modified and extended so that the developed routine is as follows A convex frame is placed on the bed, extending between, and resting on, the head and foot pieces The highest part of the arch is at about the mid-dorsal region, with two sections of the curve forming an angle of about 160 degrees The patient lies on the frame continuously Traction is applied to the head by means of a Sayre halter, and to the trunk by a pelvic belt with weights suspended from cords running over pulleys at the foot of the bed At first the patient lies on the frame for several days without any pull to permit her to become accustomed to the position It is rather surprising how rapidly this occurs, so that eating, sleeping and resting are very comfortable After a few days a pull of a few pounds is applied, and as the patient becomes accustomed to it, the weights are increased The weight on the head varies between 5 and 10 pounds (2.3 and 4.5 kg), and that on each side of the pelvis is somewhat greater When there is much antero-posterior or lateral deformity, a Balkan frame is set up, and forward or lateral traction is used in addition All traction is removed during

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<sup>4</sup> Kleinberg, Samuel Surg, Gynec & Obst **32** 364 (April) 1921

<sup>5</sup> Whitman, Royal J Orthop Surg **3** 330 (July) 1921

meals, for the morning bath, and for daily massage. It was found that in some of the cases, the children were very weak when taken off the frames, and for many days locomotion was unsteady and difficult and that the legs and feet were swollen. This has been prevented in our recent cases by daily massage of the back and legs. In this way, the

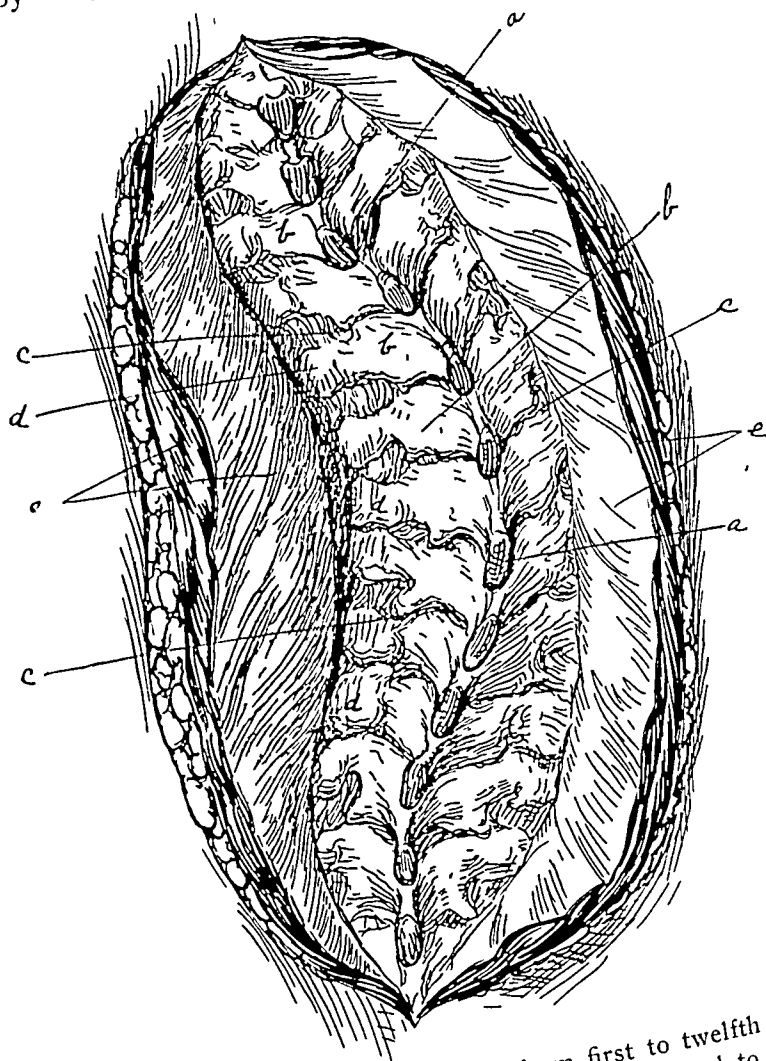


Fig 2—Exposure of posterior arches from first to twelfth dorsal vertebra. The Hibbs fusion operation is carried out from the third to the tenth dorsal vertebra, inclusive. *a*, spinous processes, *b*, laminae, *c*, articular processes, *d*, transverse processes, and *e*, periosteum and muscles.

circulatory and muscular tone has been retained and no further difficulty has been experienced in walking. When the maximum degree of correction has been obtained, the patient is ready for the operation. It came as a pleasant surprise to find that within a short time a very marked degree of improvement was seen. Apparently, relaxation of the tissues occurs during recumbency and the traction and hyper-

extended posture reduce the curvature Within from four to eight weeks, a degree of improvement is seen which would not be attained in less than six, or more, months by the method of corrective plaster-of-Paris jackets I am convinced that the maximum degree of improvement in a given case can be obtained in from one to two months by

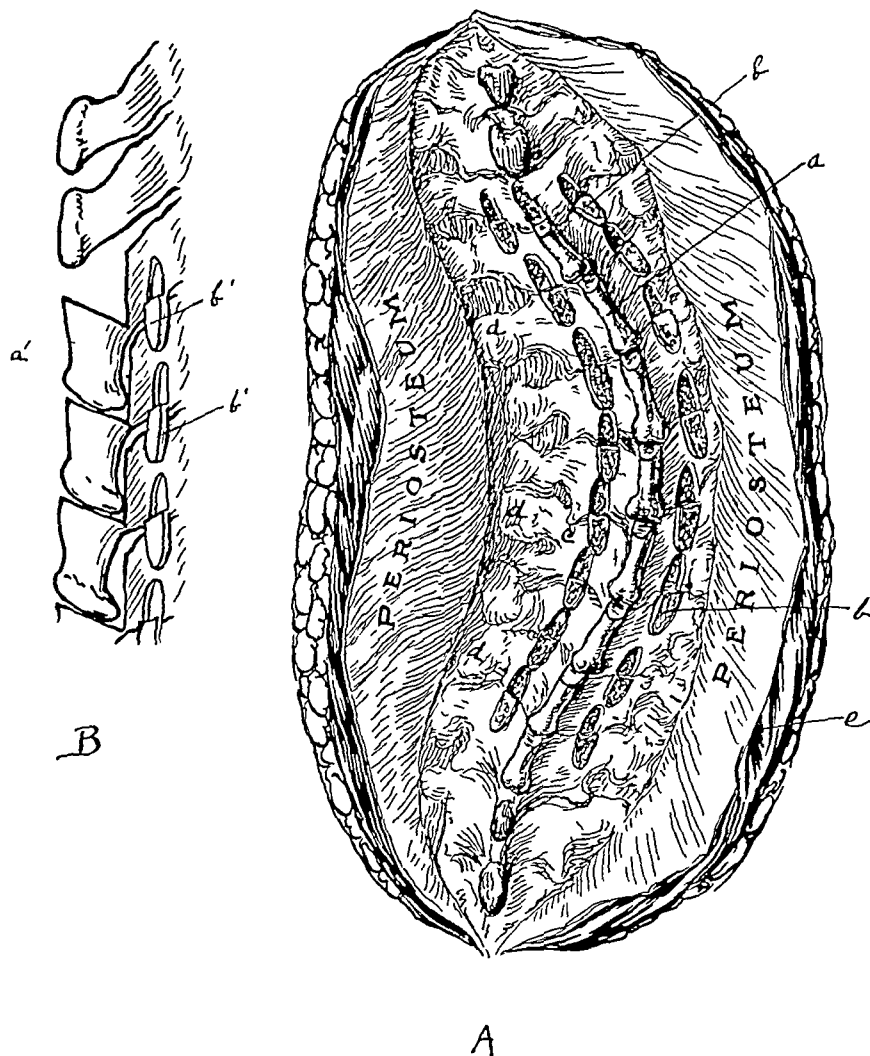


Fig 3—*A*, the Hibbs operation performed from the third to the tenth dorsal vertebra The spinous processes (*a*) have been split and turned down, the tip of one being in contact with the base of the spinous process below, *b*, pieces of bone elevated from laminae and laid across the interlaminae spaces, *c*, articulation between articular processes scarified, *d*, tips of transverse processes, and *e*, spinal muscles *B*, manner in which spinous processes are split and turned down (*a'*), small sections of bone elevated from laminae and turned down to bridge the space between adjacent laminae (*b'*)

the application of traction in the recumbent position on a convex frame It has been my experience that there is a certain degree of potential improvement in every case This degree varies in different subjects,



but when reached it seems impossible to progress beyond it. A given patient, for instance, is treated with corrective jackets. A marked change is seen in the first jacket, some further improvement is obtained in succeeding jackets. Finally, at the end of a year or more, no further change occurs no matter how much the treatment is prolonged, that is, the maximum degree of improvement for that case has been reached.

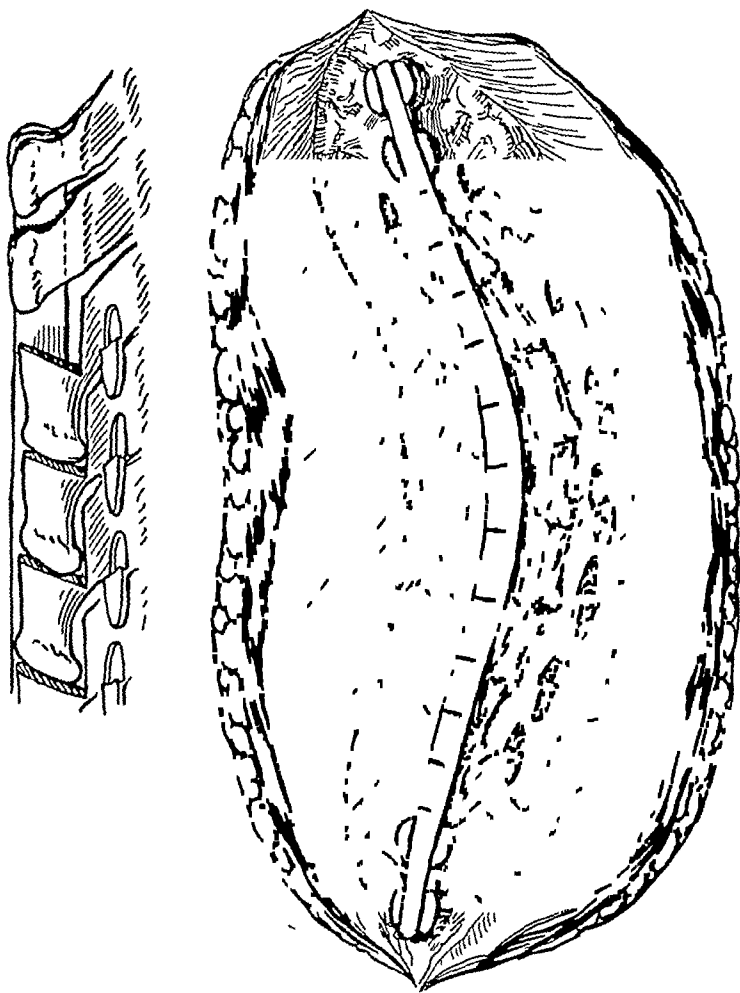


Fig 4—Beef Lone graft inserted on concave side of curve. Upper part of graft held between split spinous processes of first and second dorsal vertebrae, lower part held between split spinous processes of eleventh and twelfth dorsal vertebrae. Nicks in graft to facilitate vascularization may be noted.

Experience has taught us about how much change we may expect in the various types of deformity, and one comes to depend on his experience in judging when the greatest amount of correction has been secured. My observations lead me to believe that the maximum potential improvement is secured by this method of traction applied in recumbency on a convex frame more rapidly and with very much less discomfort than by any other procedure. The correction obtained on the

frame would be of no advantage if at the end of the brief period of recumbency and traction the patient were permitted to get up without any further support, for relapse would occur immediately. The frame treatment is of value only as a preliminary step to some means of fixation of the spine. Operative fusion of the spine appears at present to be the most effective and most desirable method of fixation.

#### PREPARATION FOR OPERATION

As aseptic healing is particularly desirable, unusual precautions to avoid infection are taken in the preparation of both the patient's back and the graft to be used. A beef bone graft, cut to the desirable shape and thickness, is boiled for several hours and placed in a closed vessel with ether. Just before the operation it is again boiled for half an hour. Transverse nicks are made in the graft in the belief that these will facilitate vascularization. All traction and massage are discontinued three days before operation. On the first of these three days, the patient's back is shaved if necessary and scrubbed thoroughly with soap and water, dried, and a voluminous sterile dressing applied. On the second day, the back is again scrubbed with soap and water and covered with a sterile dressing. On the morning of the third day, or the day of operation, assuming that the patient is to be operated on in the afternoon, the back is painted with one-half strength (35 per cent) tincture of iodine and a sterile dressing is put on. If the patient is to be operated on in the morning, the coat of iodine is used the night before. All of these details may perhaps be unnecessary, but they seem advisable, and inasmuch as I have not yet had an infection in a case of spinal fusion, I believe that these procedures have contributed some share, at least, to the satisfactory aseptic healing.

#### OPERATION

The operation, as I have performed it, combines the technic of the Hibbs and Albee methods. It includes most of the vertebrae of a simple curve and all of the vertebrae of the dorsal segment of a compound curve. The dorsal is the most favorable site for operation. This is so because the vertebrae are more easily reached in this region and because the elimination of motion here is of less consequence than in any other part of the back. An incision of the desired length is made through the skin and subcutaneous tissue. Following the method of Hibbs, the periosteum and overlying muscles are elevated from the spinous to the tips of the transverse processes, that is, the posterior arches of the vertebrae are thoroughly denuded and exposed. This part of the operation should be performed as nearly as possible subperiosteally, for troublesome hemorrhage is thus avoided. The joints of the articular processes are then scarified or destroyed. Chips of

bone are chiseled away from the laminae and placed across the inter-laminar spaces. The spinous processes are split at their bases and turned down so that the tip of the spinous process above fits into the space at the base of the spinous process below. At times I have split the spinous processes into several horizontal sections which have been spread out into a fanlike mass (Forbes' method). When this part of

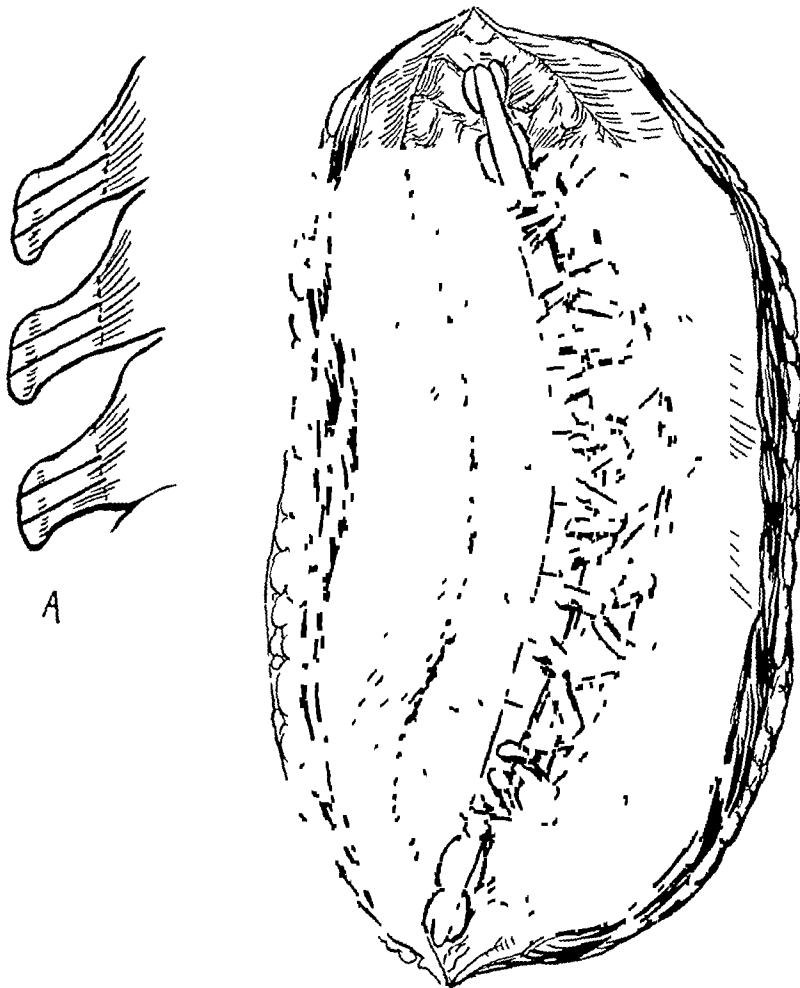


Fig 5—Spinous processes split according to the Forbes technic and the sections of the spinous processes laid in different directions, forming a large bony area for contact with the graft *A*, lateral view showing manner of splitting spinous processes according to the Forbes technic

the operation is complete, the spinous processes of two vertebrae above the upper limit and of two vertebrae below the lower limit of the curve are split (Albee technic). The latter vertebrae, being at the points of transition from the main to the compensatory curves, are rarely deformed to any degree, and the spinous processes are practically in the median line. A graft sufficiently long to reach between the limits of the vertebrae operated on, about one-fourth inch (6 mm) wide and some-

what less in thickness, with a curve that corresponds to, but is not so marked as, the curvature of the spine, is laid in the wound, being placed on the laminae and transverse processes on the concave side of the curve, with the extremities of the graft embedded between the segments of the split spinous processes. The graft is thus brought into contact with a large mass of bleeding bone consisting of the transverse processes, laminae and spinous processes. When the spinous processes are split into several sections, I place them on top of the graft. They serve to hold the graft down and bring more of its surface in contact



Fig 6—Arrangement of bed and convex frame used in the treatment of scoliosis at the Hospital for Ruptured and Crippled

with living bone. The periosteum and muscles are sewed with interrupted kangaroo sutures. The subcutaneous tissue and skin are closed with separate layers of catgut. A dressing is applied and a warm sterile flannel jacket is put on and the patient returned to bed.

#### RATIONALE OF THE OPERATION

Experience has shown that it is very difficult and often absolutely impossible, as well as dangerous, in the *severe cases* of scoliosis completely and thoroughly to denude the posterior arches of the vertebrae of periosteum, that is it is not possible to perform the typical Hibbs operation. I have therefore used a stout bone graft with two objects

in view First, as a strong mechanical support extending between the ends of the curve, the graft will prevent increase of the curvature during the healing and consolidation Second, as in the course of time this huge mass of bone is absorbed, it will be replaced by new bone so that there will be in the region of the curvature a very large and solid mass of bone (greater perhaps than results from the simple Hibbs fusion) which will join the vertebrae, prevent increase of deformity



Fig 7—Roentgenogram of bov (S P) with paralytic structural scoliosis, taken, May 22, 1921, a few days before he was placed on the frame

and thus be instrumental in arresting the progress of the deformity Whether the hoped-for result will be obtained remains to be proved

#### POSTOPERATIVE CARE

The operation, involving as it does rather rough handling of the vertebrae, pulling, pushing, scraping, chiseling, hammering, some bleeding and an anesthesia of not less than an hour, and usually nearer an hour and a half, is accompanied practically always by some shock

The patient is, therefore, put back to bed and not on the frame. When extra heat is necessary, it is supplied by means of therapeutic lamps and portable baking machines. This simple, but very helpful, procedure was suggested by Armitage Whitman. Extra blankets are supplied and, if necessary, medication. It usually takes three or four days before the patient begins to feel comfortable and the pulse returns to the preoperative normal.

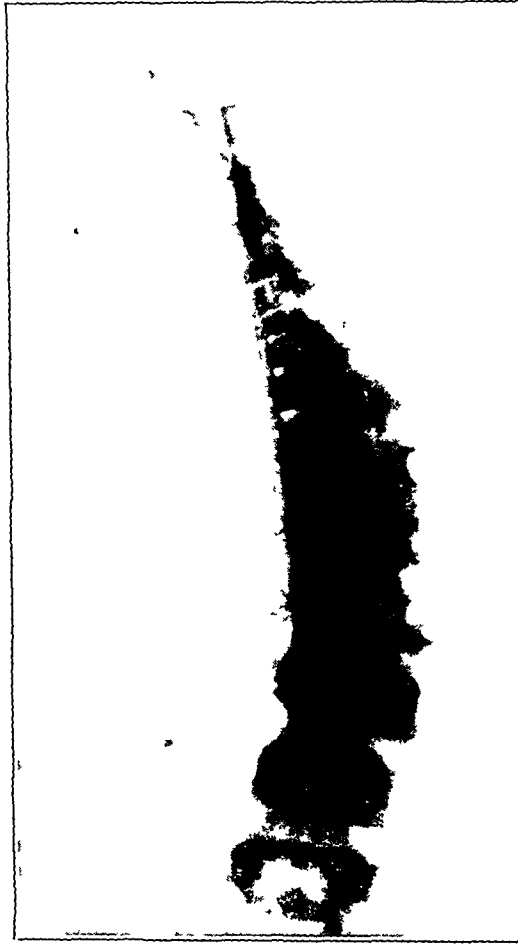


Fig 8—Patient (S P) treated on frame until July 19, 1921, when he was operated on. This roentgenogram was taken, Sept 22, 1921, while he was still on the frame and shows reduction of curve of spine and graft in place. The improvement in the appearance of the back is greater than the apparent reduction of the curvature of the spine.

When the patient has completely recovered from the immediate effects of the operation, that is, in a week or ten days, she is replaced on the frame. Traction is applied so that the maximum degree of improvement of the back is retained while consolidation and bone for-

mation are taking place. It is hoped then that the union or fusion of the vertebrae will take place with the spine in the most favorable and least curved or deformed condition. This usually means a postoperative period of treatment of not less than eight weeks. During this time, the patient receives massage and exercises of the limbs.

At the end of this period, we have found that the patient is usually able to stand up and retain the improvement. Fearing, however, that



Fig. 9—Case (M. J.) of idiopathic structural scoliosis, July 21, 1921, treated by corrective exercises for one year. Deformity growing worse.

the union may not be sufficiently solid, additional support in the form of a light, well-fitting plaster jacket is continued for several months.

The entire treatment lasts between six and nine months, and I believe that in this comparatively short period the same results may be accomplished as were formerly obtained by the corrective jacket method in several years, and with the likelihood that there will not be any relapse.

Although the operation does not remove those particular factors (whatever they are) which are responsible for the rotation and deviation of the vertebrae, and although it is appreciated that a solid spinal column may, like a single long bone, such as the tibia or femur, become deformed, yet it seems reasonable to believe and we are encouraged in this belief by our recent experience that when from eight to twelve vertebrae are fused into a solid mass, there will be little, or less, tendency toward increase of deformity

#### RESULTS OF TREATMENT

Our experience with the system of treatment outlined has not extended over a sufficiently long period, nor does it include a large enough series of cases, to permit absolutely positive conclusions, but the results have been highly satisfactory and justify its use on a large scale. The preoperative, or corrective, treatment affords an opportunity to obtain the same degree of improvement resulting from the employment of other methods and has the distinct advantage of taking very much less time than is necessary when using jackets, braces or exercises. In addition, it is entirely free from the restraint and discomfort of jackets or braces. Atrophy of the muscles may be avoided by daily massage and exercise on the frame. The permanency and value of fixation of the spine must be left to future judgment.

The immediate results have been satisfactory in all of the cases. The appearance of the back has been improved. In all but one case, the curvature of the spine was reduced. In the one case, that of a girl, aged 17, with an extremely severe scoliosis, the curve of the spine was not reducible. The operation was performed because the deformity was becoming more severe and it was hoped that the spinal fusion would "fix" the spine and prevent increase of the curvature. This patient has already gone without any support for several months and so far the deformity has not increased. Five other patients of my series have been without any support for periods varying between two and six months and have retained the improvement. In these cases, the fixation has been successful, for the operative region of the spine remains immobile. In two instances, there is noticeable fragmentation and partial disappearance of the graft. As there is no large amount of callus (as far as one may judge from roentgenograms), it is impossible to say whether the graft has been replaced by new bone. However, the stiffening of the spine persists.

Up to date, I have operated on nineteen patients, twelve girls and seven boys. The ages varied between 8 and 20 years. Three cases were paralytic and the others were of the idiopathic type. I believe that fixation and at least fibrous ankylosis were obtained in every instance. Fixation of the spine was judged clinically by the loss of motion. The



loss of flexion and extension was determined by the lack of motion in the anteroposterior plane when the lumbar region was immobilized. It was difficult to decide about the absence of lateral motion in the dorsal region, because it was hard to eliminate, by ordinary manual support, all lateral motion between the lumbar vertebrae. Roentgenograms were used to help us in this connection. They were taken with



Fig 10—Same patient as in Figure 9, treated on convex frame from July 21, 1921, to Sept 13, 1921, when he was operated on. This roentgenogram, taken Oct 10, 1921, while the patient was still on the frame, shows reduction of curve and graft in place.

the patient bent laterally, first to the extreme right and then to the extreme left. In several cases in which this test was used, there was apparently no lateral motion between the vertebrae operated on, and the fixation was seemingly complete.

It has thus far been impossible to judge from the roentgen-ray appearance alone whether there was osseous fusion of the vertebrae

In none of the cases was there any large amount of bone thrown out at the site of operation. But in a number of instances, there was marked haziness and partial obliteration of the intervertebral spaces. This was interpreted as signifying deposition of new bone presumably uniting the posterior arches.

As previously mentioned, we have not limited ourselves to paralytic cases and we believe that the treatment is applicable to all varieties of scoliosis. It is manifestly not indicated in a case which has remained stationary for a number of years, nor should an operation be performed on a patient who is so markedly deformed that she is not likely to become worse. To be of the greatest value, the operation should be performed in the mild cases, so that the more advanced degrees of deformity may be prevented.

#### SUMMARY

The treatment of structural scoliosis by the method outlined, consisting of a period of correction by means of traction on a convex frame followed by operative fixation of a large number of vertebrae by denuding the periosteum from the posterior arches of the vertebrae and inserting a large and long beef bone graft, has given very satisfactory results and appears to be a distinct improvement and advance in the management of this most troublesome of all deformities.

The use of the beef bone graft has many advantages. It may be prepared in advance, so that the operation is not needlessly prolonged. It may be cut of the desired length, shape and thickness. It affords support during consolidation of the vertebrae on which operation has been performed. It acts as a framework for new bone formation. It is especially valuable in the severe cases in which the deformity of the ribs and vertebrae is so marked that it is impossible and unsafe to carry out the Hibbs fusion operation thoroughly.

The discomfort and disadvantages of plaster-of-Paris jackets are avoided and the surgeon is spared much hard work. The entire period of treatment is very much shortened, and it is hoped that it may not exceed nine months. Corrective treatment can be carried out more rapidly and just as efficiently on a convex frame with traction as by plaster-of-Paris jackets or braces.

Finally, the results obtained compare more than favorably with those following the use of plaster-of-Paris jackets, braces or gymnastic exercises.

# BONE REPAIR FOLLOWING INJURY AND INFECTION <sup>†</sup>

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NEW YORK

Since McEwen's classical work on bone repair, there has been much uncertainty in the minds of clinicians regarding the process that occurs in bone repair following injury. Whether or not the periosteum is the all-important factor in osteogenesis has clouded our minds. The significance of the bone cell, of the periosteum, and the significance of intermembranous or of intercartilaginous bone development is not known. The terms after long usage are established as entities, thus tending to suggest biologic differences because of microscopic difference. Until the physical chemist gets at the root of things, confusion concerning bone in all parts of the body will exist in the minds of laboratory workers. I believe when the real secrets of bone formation are understood, we shall acknowledge that osteogenesis occurs in the same manner in all tissues. The tissues that are seemingly different under the microscope, I believe, are chemically similar whenever osteogenesis occurs, be it repair in a fracture or repair following infection, be it in periosteum, in muscle planes, in artery wall or in the ventricular septum of the heart. Stop and think of the confusion which necessarily follows, when at best only microscopic sections can be seen of the various complex tissues manifesting bone formation at single stages of each experiment. The physiologic chemist is handicapped in the same manner because his analysis by necessity is of a single stage, always involving many tissues. In the human being, and in the laboratory animal used for experiment, the tissues are far too complex in their functional activities and structural make-up to make it possible for the observer to deduce what happens in single cells such as may be present in osteogenesis, hence, the confusion among experimenters as expressed in the literature. The surgeon is too likely to feel that he does not know much about bone repair because he is so confused by the differences of opinion of the various experimenters. Those interested in osteogenesis are as often as not disputing over names and terms rather than discussing processes, and bone formation is truly a process and not a state.

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\* From the Laboratories of the Department of Surgery, Columbia University College of Physicians and Surgeons

\* Read before the Annual Meeting of the Colorado State Medical Society, Pueblo, Oct 6, 1921



Fig 1—Early bone formation following fracture *A*, cartilage, *B*, new bone, *C*, connective tissue. Gradual transitions are observed from connective tissue to cartilage from connective tissue to bone and from cartilage to bone. No distinctive cells are seen.



Fig 2—Scrapings removed from fractured humerus of a human being twelve days after injury A, fibrocartilage, B, early bone, C, connective tissue



Fig 3—Ossification occurring in the midst of muscle fibers, twelve days following a fracture of the humerus in an adult A, ossification occurring in cartilage, B, early bone, C, connective tissue, D, degenerating muscle fibers

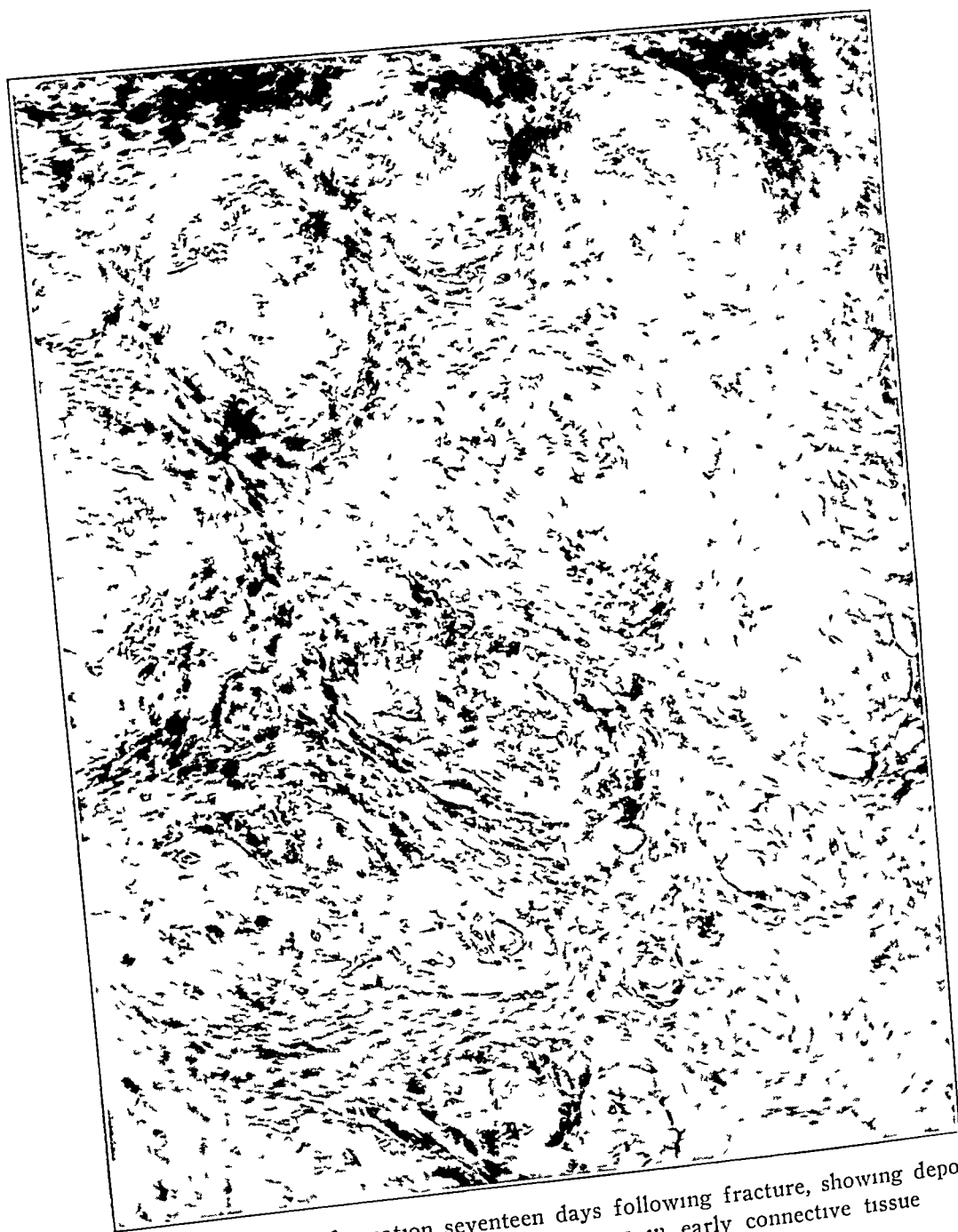


Fig 4—Callous formation seventeen days following fracture, showing deposition of calcium salts on the avascular zones in early connective tissue

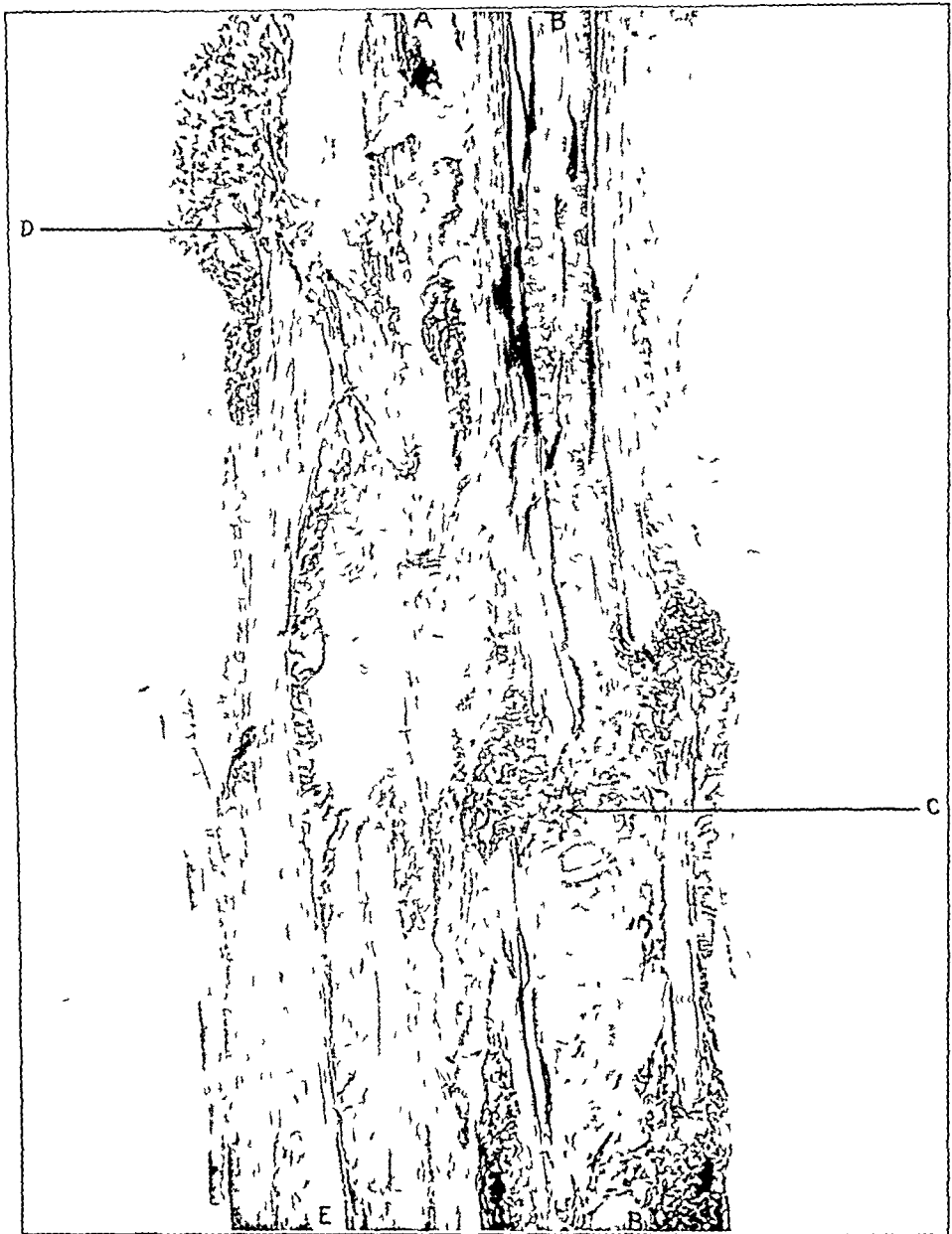


Fig 5—Comminuted fracture of radius and ulna in rabbit, fourteen days after injury *A* interosseous membrane, *B*, medullary canal of radius with cortex on either side, *C*, new bone forming in connective tissue following hemorrhage around the fractured ends and across the medullary canal, *D*, detached bone fragments surrounded by new bone formation, *E*, medullary canal of ulna





Fig 6—High power magnification of radius and ulna shown in Figure 5  
*A*, end of fractured shaft showing atrophy at end with absence of bone nuclei,  
*B*, new bone formation in the connective tissue, *C*, areolar connective tissue  
with newly formed blood vessels



Fig 7—Bone transplants four weeks following operation *A*, haversian canal with reestablishment of blood supply and surrounded by one or two layers of active bone nuclei, *B* absence of nuclei in bone distant from haversian canal



Fig 8—Transplantation of bone fragments to fill defect in radius, 141 days following operation A, ulna, B, radius, C, bone fragment, nuclei do not stain, areas of rarefaction near periphery, D, new bone formation about periphery of fragments, E, cartilage forming false joint

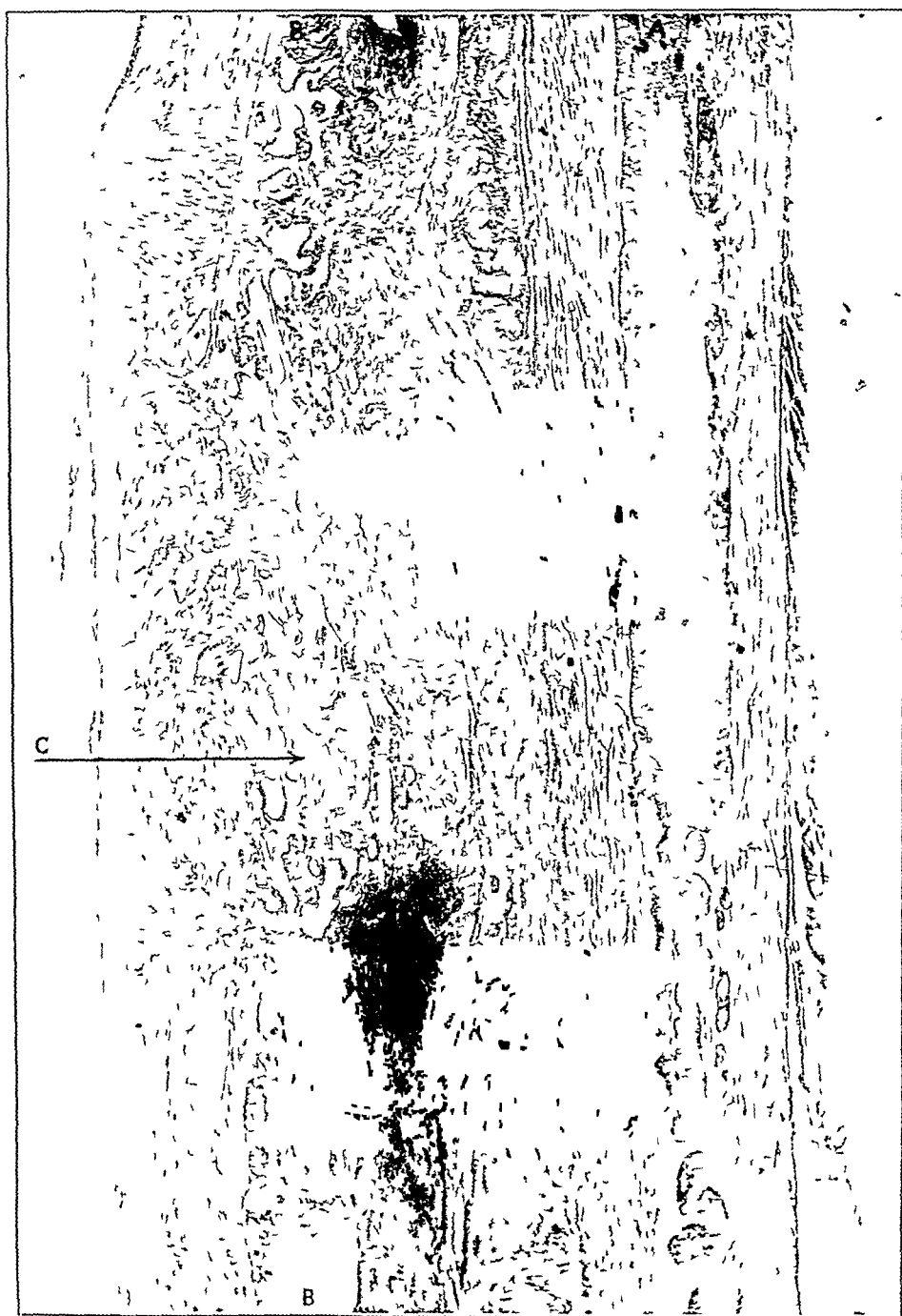


Fig 9—Transplantation of bone fragments to fill defect in radius, 347 days following operation 4, ulna, B radius C beginning formation of medullary canal The entire zone shown in the illustration is the area in which the transplants were placed It is no longer possible to detect the fragments but a new cortex and medullary canal are being established by the gradual absorption of the fragments and the formation of new bone

In order to have satisfactory therapeutic results, it is advisable to accept some practical working theory that will cover all types of bone formation. This theory should be broad enough not only to cover the skeletal bone formation but also the extraskeletal bone formation

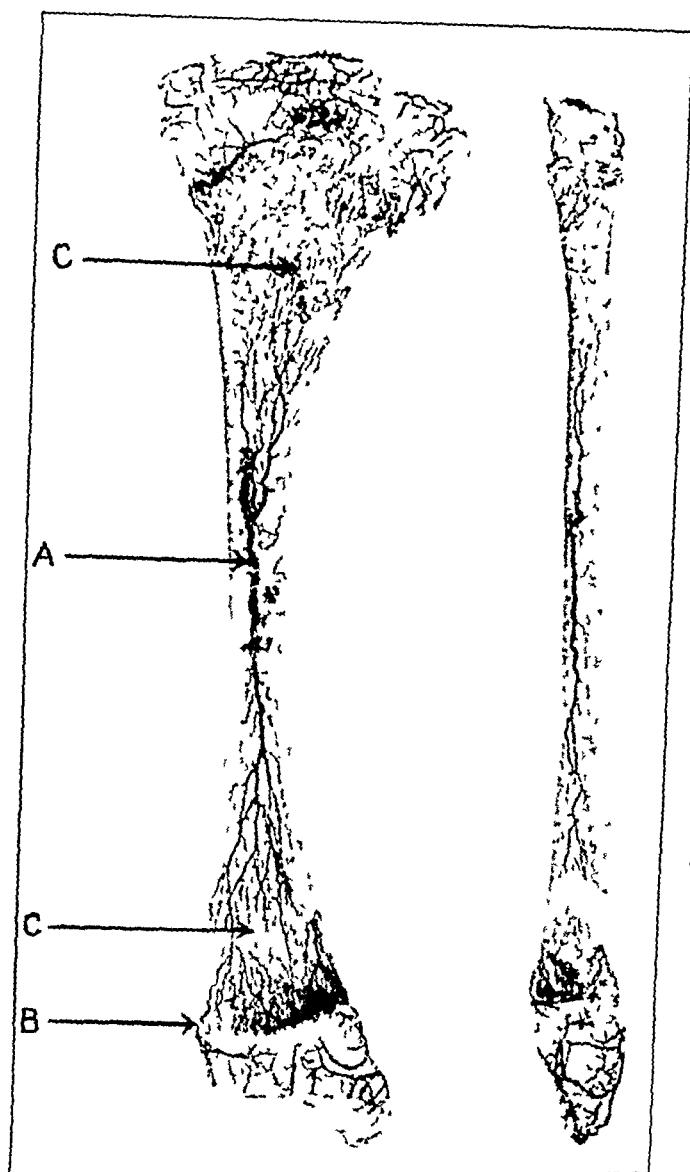


Fig 10—Circulation of infant's tibia and fibula (after Lexer) *A*, nutrient artery, *B*, metaphyseal capsular artery, *C*, relative avascular zone, where sequestrum separation usually occurs

that occurs in so many places in the body. Extraskeletal bone formation occurs in one or more tissues in all of us if we live long enough and it may be produced experimentally in animals without difficulty. Extraskeletal bone occurs frequently in man in the arterial wall and

in the muscles. It has been described as having been found in nearly all of the tissues of the body, such as the lymph nodes, ovaries, kidneys, fascial planes and wall of the orbit.

Experimentally, bone has been produced in animals by ligating the vessels of the kidney and wrapping the omentum about it. Microscopic sections of this kidney from one to two months later show areas of true bone and calcification occurring in the parenchyma. Neuhoff,

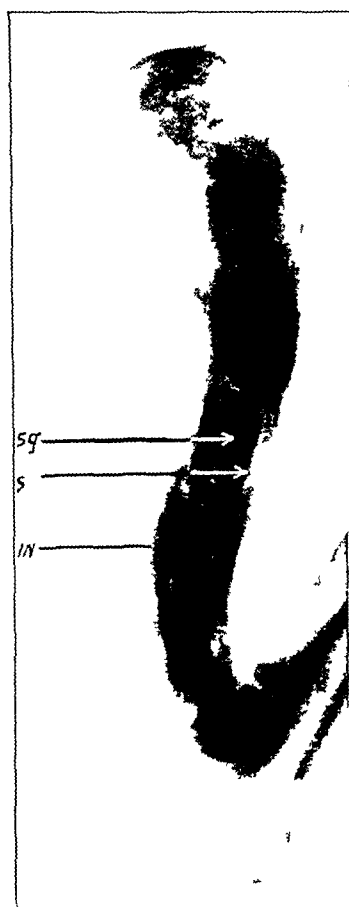


Fig 11—Roentgenogram of humerus, Nov 3, 1919. Croton oil was inserted into the medullary canal in capillary tube containers, Oct 10, 1919. SQ, sequestrum, IN, involucrum, S, separation zone.

working in the laboratory of surgical research at Columbia University, found bone almost universally in fascia lata transplants that he had made to fill a defect in the bladder. Any theory, therefore, that we may accept should be broad enough to explain these irregular types of bone formation as well as the repair of bone following fractures and infection. We may, for the sake of discussion, classify the theories of bone repair roughly into three groups: (1) periosteal, (2) osteoblastic and (3) extracellular deposition of calcium salts.

1 The periosteal theory presupposes that the periosteum and endosteum are definite organs for bone formation and repair, and that the bone cells arise from them and from no other source

2 The osteoblastic theory may be divided into two subtitles

Type A This assumes that in bone repair following injury bone cells are liberated from their lacunae and that they reproduce and form new bone

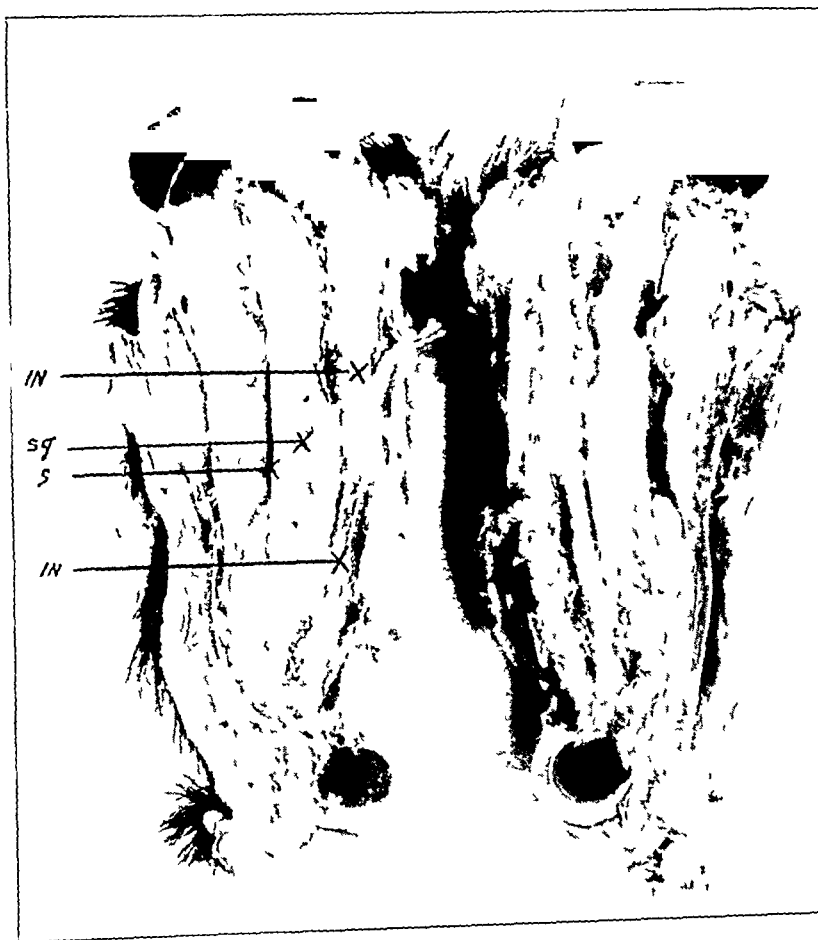


Fig 12—Cross-section showing massive sequestrum extending almost the entire length of the shaft, SQ, sequestrum, In, involucrum, S, separation zone

Type B This assumes that following injury wandering connective tissue cells, fibroblasts, are drawn into the area of trauma. Owing to the stimulus of the repair, they are transformed into bone producing cells and then become specific cells

3 The extracellular deposition of calcium salts theory assumes that there is no definite bone producing cell, that following injury, possibly by positive chemotaxis, calcium salts in the proportions usually found

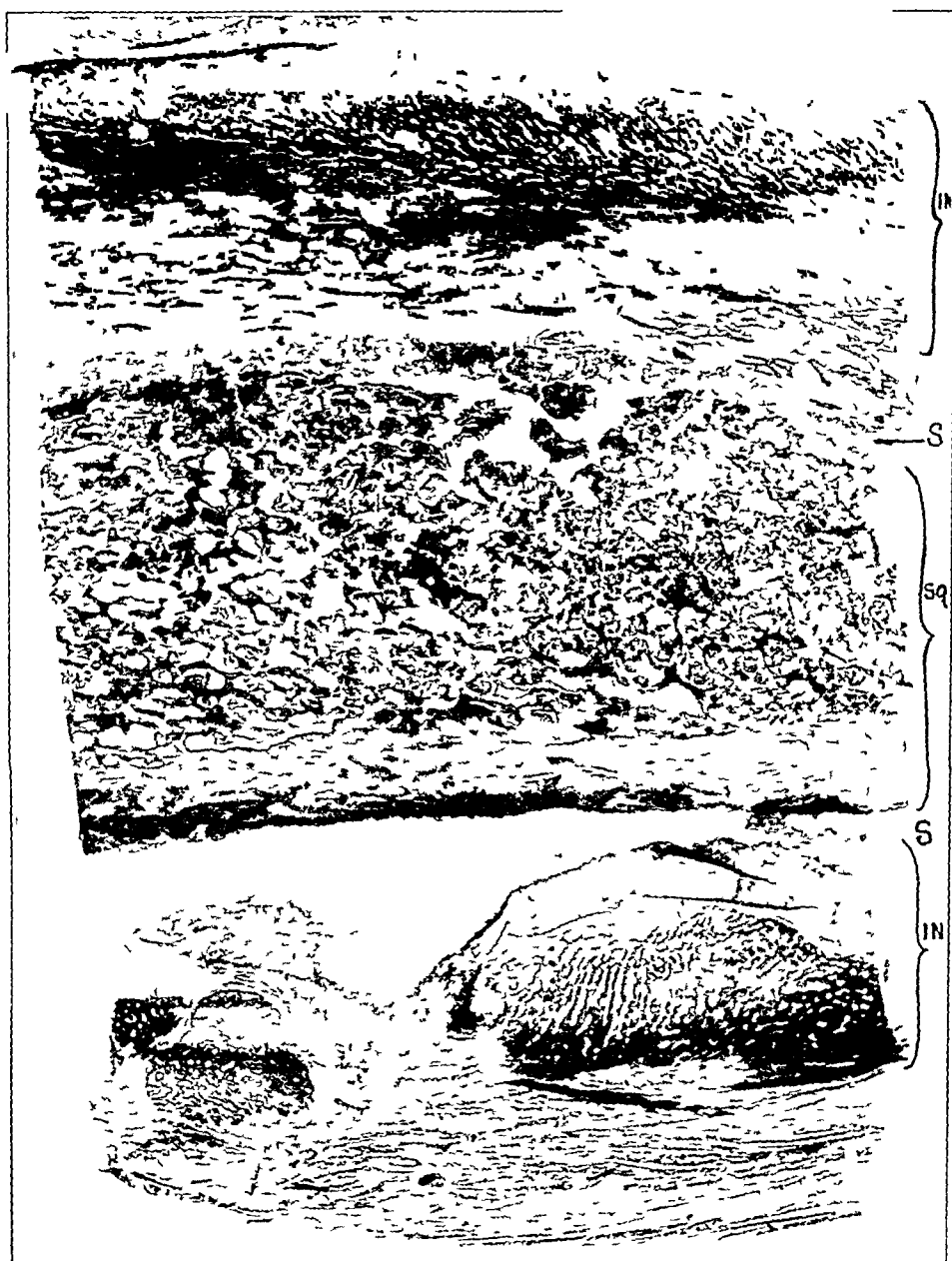


Fig 13—Microscopic section *Sq* sequestrum *In* involucrum, *S* separation zone Under high power magnification the bone nuclei in the sequestrum are absent and the zones in the medullary canal are filled with leukocytes The separation zone *S* contains debris and numerous polymorphonuclear leukocytes In the lower separation zone *S* debris disappeared during the process of decalcification



in bone are deposited in the extracellular frame-work of connective tissue and that the connective tissue cell then becomes a bone cell by functional adaptation

Any one of these three theories may explain the ordinary repair of bone as seen in fractures, but it is difficult to explain under the periosteal theory the formation of extraskkeletal bone

The bone in fascia lata transplants in the bladder found by Neuhoff cannot be explained by the periosteal theory, and it is difficult to explain

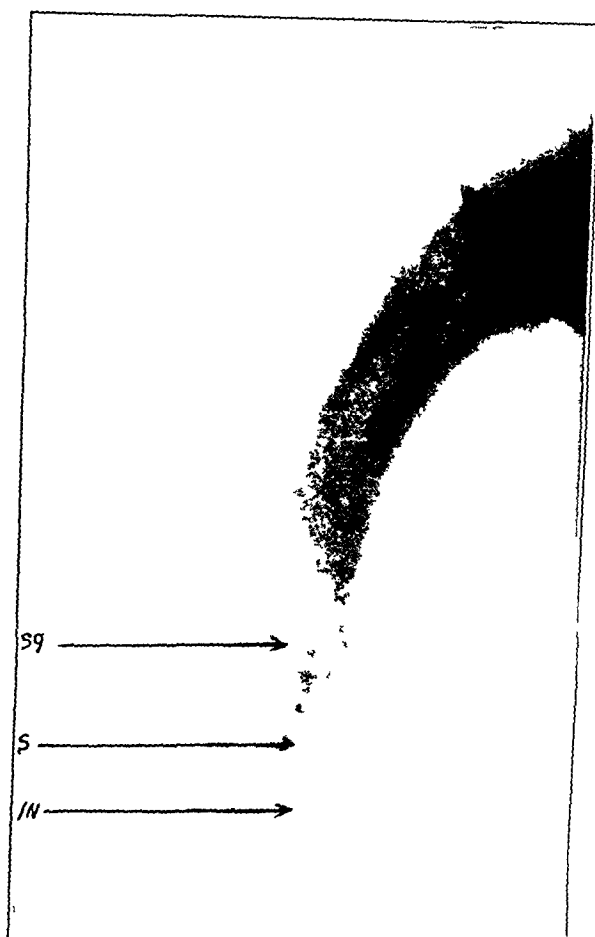


Fig 14—Following insertion of capillary tube containing croton oil, in medullary canal, Sept 21, 1920 Roentgen ray Large sequestrum in upper half of humerus, Oct 15, 1920

it if we assume that the osteoblast is a specific cell coming from other bone cells Moreover, it is impossible to explain the formation of bone in the arteries of human beings, in the lymph nodes or in the kidney by either of these theories

If we assume that bone is formed by metaplasia of connective tissue cells into osteogenetic cells or if we assume that it is purely a chemical deposition in living connective tissue, we may explain the phenomenon very easily

The third theory has seemed more plausible to me. Gideon Wells has shown that if cartilage is transplanted into the omentum it has a greater power of absorbing calcium from the blood than has any other tissue similarly placed. He believes that the same proportions of calcium phosphate and calcium carbonate are present in the ash of calcified material as bone, the main difference being that calcification occurs in dead tissue while ossification occurs in the presence of living tissue. In sections of kidneys in which the vessels have been ligated

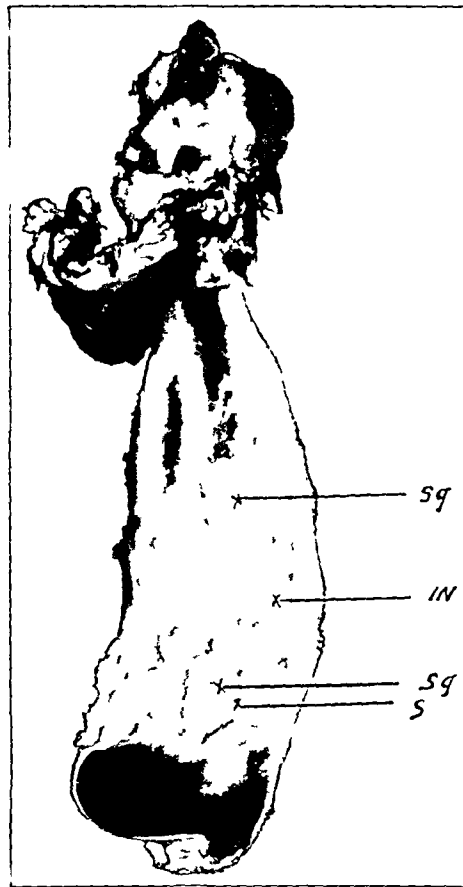


Fig 15—Cross-section showing massive sequestrum, with thick involucrum and zone of separation. *SQ*, sequestrum, *In*, involucrum, *S*, zone of separation

there are zones of calcification and ossification, the calcification occurring in dead tissue and ossification occurring where living bone cells are observed.

The simplest type of bone repair is seen following fractures. In a series of fractures on animals, I have been able to follow the repair at various stages. Immediately following the fractures, there is hemorrhage between the broken ends. Fibrin is then deposited and con-

traction of the clot occurs. In from about five to ten days the organization of the clot by the ingrowth of connective tissue occurs. Connective tissue appears to take a definite lobulated arrangement, so that if we look at a cut section, we find blood vessels and then areas of thin areolar connective tissue (Figs 1 to 4).

Calcium salts are then deposited in the avascular zones between the blood vessels. Early callus looks very much like the lobules of the



Fig 16—Lower power magnification of terminal portion of sequestrum with surrounding involucrum. *A*, sequestrum, *B*, granulation tissue, *C*, involucrum, *D*, terminal spicule of sequestrum shown under high power in Figure 17.

liver. At first the blood vessels appear about this area of areolar tissue and then an area of new bone appears. At a later period, the areolar zone is almost completely replaced by osteogenetic tissue. This process continues until there is a definite haversian canal system of adult bone. In the zones of exuberant callous formation, absorption of the calcium salts takes place and scar tissue results. Bone atrophy occurs almost universally near the fractured ends. A great number of nuclei of the bone cells in the lacunae disappear.



Fig 17—Terminal portion of sequestrum showing new bone formation about it, and gradual reorganization *A*, dead bone, cell spaces are empty showing no nuclear stain, *B*, newly formed bone surrounding and incorporating dead bone

As the granulation tissue springs from the periphery and the new blood vessels run at right angles to the shaft, the haversian canals as seen by microscopic examination from three to five months following fracture, are perpendicular to the normal haversian canals of the shaft. At the end of a year, however, by a gradual process of absorption and new formation, canals are reestablished in a normal direction. Periosteum, as it is a connective tissue and as it has an areolar layer

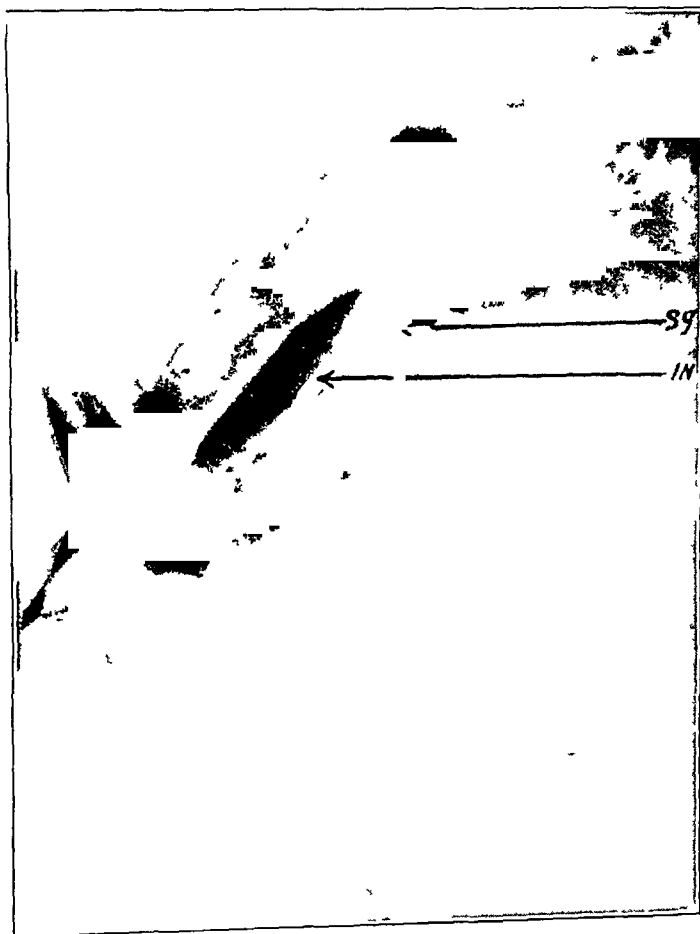


Fig 18—Large sequestrum, Nov 10, 1919, with well marked involucrum and separation zone *In*, involucrum, *Sq*, sequestrum, operation performed, Oct 10, 1919

immediately adjacent to the shaft, undoubtedly serves as a bone forming membrane, but it is not the only connective tissue which may form bone (Figs 5 and 6)

The study of bone grafts shows strikingly why the clinician and the laboratory worker have differed in their accounts of the after-history of the graft

The clinician has usually stated that grafts "live," because if occasion should arise demanding the performance of a secondary operation,

he finds that the cut section of the graft bleeds and that it has the general appearance of living bone. Roentgenograms also show the graft appearing as normal bone.

The laboratory worker on microscopic examination finds that in grafts of one to two weeks' duration the nuclei do not stain and the bone appears dead. Microscopic examination at a later period reveals the blood vessels reestablished in the haversian canals, and about them one or two layers of living bone cells, while portions of the graft

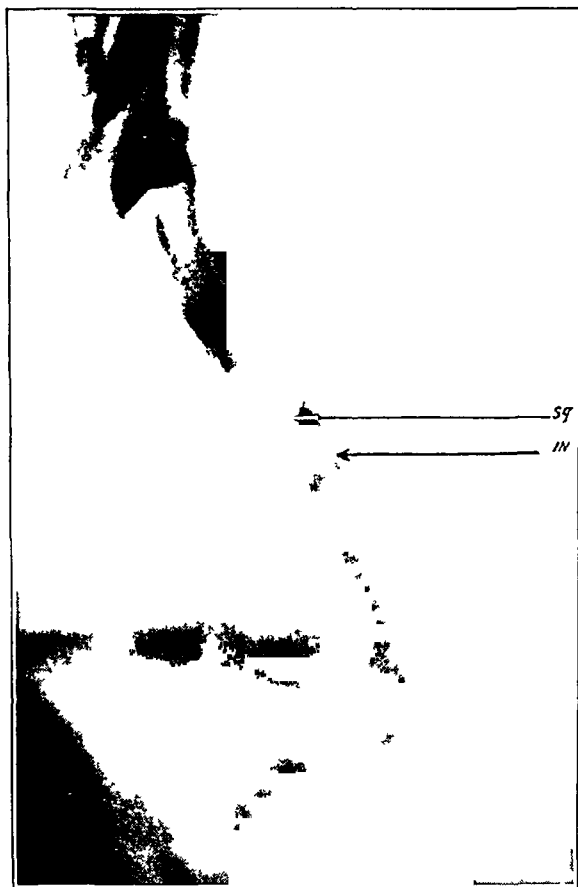


Fig 19—Sequestrum and involucrum, Dec 1, 1919, less marked than previously. *In*, involucrum, *Sq*, sequestrum.

further from the canals show the absence of nuclei (Fig 7). The process then continues as a gradual absorption of the dead bone and the formation of new bone in its place. It is easy to see that the bone at this period would bleed on section and would appear alive clinically.

In order to have a successful graft, three conditions must be established. First, the graft must maintain the shape of the limb, second, it must have its blood supply quickly reestablished and, third, it must stimulate osteogenesis in the neighboring tissues.

McWilliams, in a thorough analysis of the various methods of bone grafting, read before the American Surgical Association at Toronto in June, 1921, came to the conclusion that the presence of periosteum upon the graft had very little influence upon its ultimate success. He analyzed about 1,390 cases in which grafts had been used. Of these, 1,170, with 82.9 per cent of successes, had periosteum, while 196, with 82.6 per cent of successes, were without periosteum. In

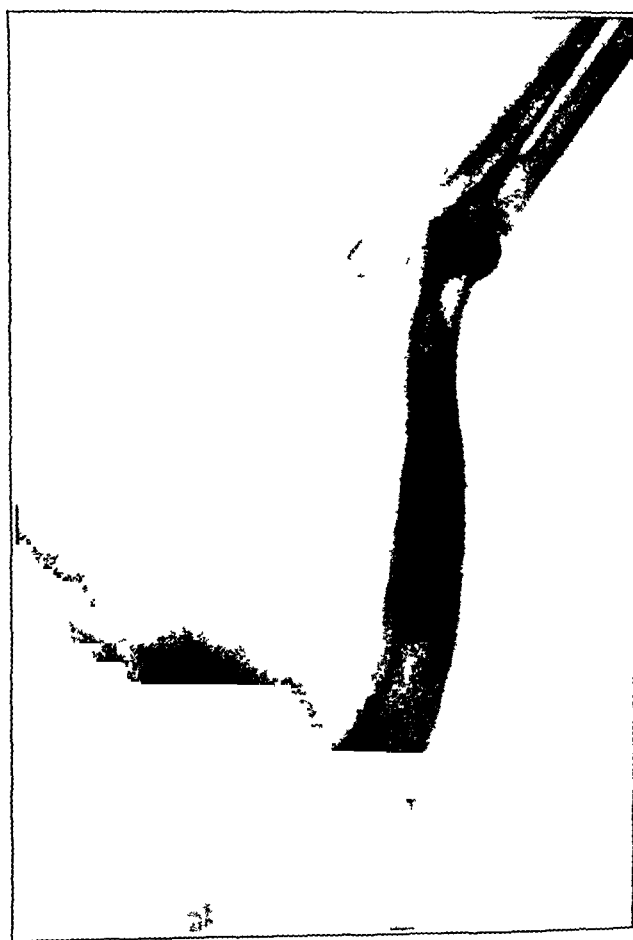


Fig. 20—Roentgenogram, Jan. 15, 1920, no involucrum or sequestrum seen

analyzing the types of transplants, he found that the successes were relatively as follows: bone pegs, 95.8 per cent; osteoperiosteal (Ollier, DeLangeniere), 87.3 per cent; end-to-end (without inlay), 82.5 per cent; inlay, 80.9 per cent; and intramedullary, 76.6 per cent.

If we study these, we find that probably the three points emphasized for the success of bone grafts explain the relative success of the foregoing methods:

Bone pegs are surrounded completely by bone and very quickly have their blood supply reestablished

The osteoperiosteal grafts of DeLangeniere are thin strips of bone and periosteum which are laid down between the ends of the bone. If they are sufficient to maintain the shape of the limb, theoretically they are the most practical, for the blood supply is very quickly established. They offer a large surface of raw bone to stimulate osteogenesis.

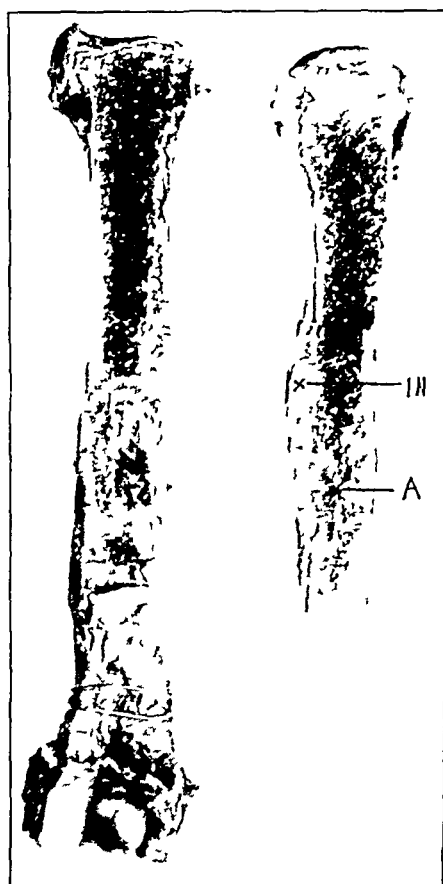


Fig 21—Cut-section, Jan 24, 1920. *In*, subperiosteal bone proliferation, *A*, probable remnants of old sequestrum but no separation zone.

The inlay graft is, as a rule, rather thick and does not offer so much surface of raw bone for stimulation of osteogenesis. The late fractures that occur in these cases are probably due to the slow reestablishment of the blood supply and the resulting atrophy of the transplant.

I am inclined to believe that the intramedullary graft should be condemned. We know that the main blood supply of the shaft of the long bone is from the nutrient artery. In applying an intramedullary



graft, we destroy the blood supply of both fractured ends of the shaft and undoubtedly a longer time is required for repair on account of this to reestablish the blood supply of the graft

In a series of experiments lasting over two or three years, I transplanted small bone fragments into a defect of from 1 to 2 inches (2.5 to 5 cm) in the radius of dogs. Microscopic studies made at various intervals after operation showed, in the early stages, absence of the nuclei in all these grafts. There was, however, marked production



Fig 22—Microscopic section showing subperiosteal bone proliferation, no zone of separation *A*, spaces in which capillary tubes lay, *B*, artefact occurring during decalcification

of new bone about them in the granulation tissue produced immediately after operation. Firm union was the ultimate result in nearly all of these cases.

At the end of about a month, blood vessels were seen in the haversian canals of the fragments, and about each of these canals were seen two or three layers of bone cells with active nuclei. I believe that these grafts act in a manner similar to the osteoperiosteal grafts of DeLangeriere (Figs 8 and 9).

## OSTEOMYELITIS

At the present time, when radicalism is necessary in the treatment of chronic osteomyelitis in adults, I believe a word of caution should be spoken with regard to the treatment of hematogenous osteomyelitis in children

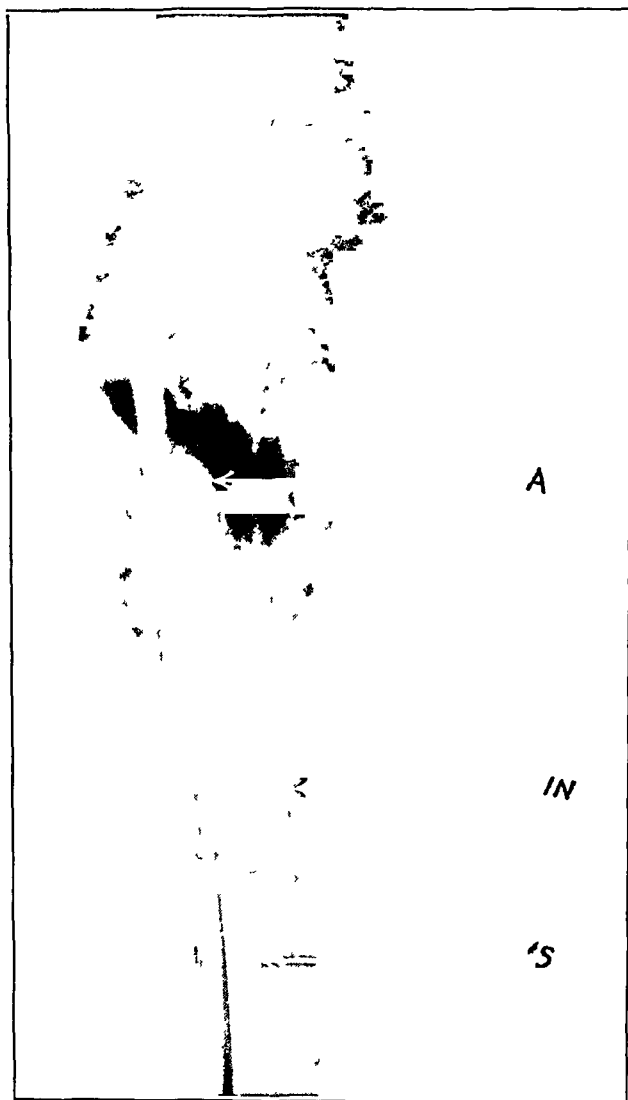


Fig 23 (Case 1)—Roentgenogram, taken July 30, 1919, operation performed June 22, 1919, consisting of removal of 2 inches (5 cm) of anterior surface of the upper third of the tibia *A*, area of bone removed at primary operation, *In*, involucrum, *S*, separation zone

The treatment of acute osteomyelitis in children may properly be divided into the treatment at the acute, and treatment at the subacute, stage. The primary indication for operation at the onset is the relief of pus under pressure, and as such, it requires the application of the

same surgical principles as pus collections elsewhere in the body, that is, adequate drainage, with the least possible trauma and with careful attention to the blood supply. If one considers that frequently periosteum with its blood supply has been stripped from the shaft by the exudation of pus and that the only remaining blood supply to the shaft is through the nutrient artery, one realizes the danger to the entire shaft of too active treatment by curettage or packing (Fig 10)

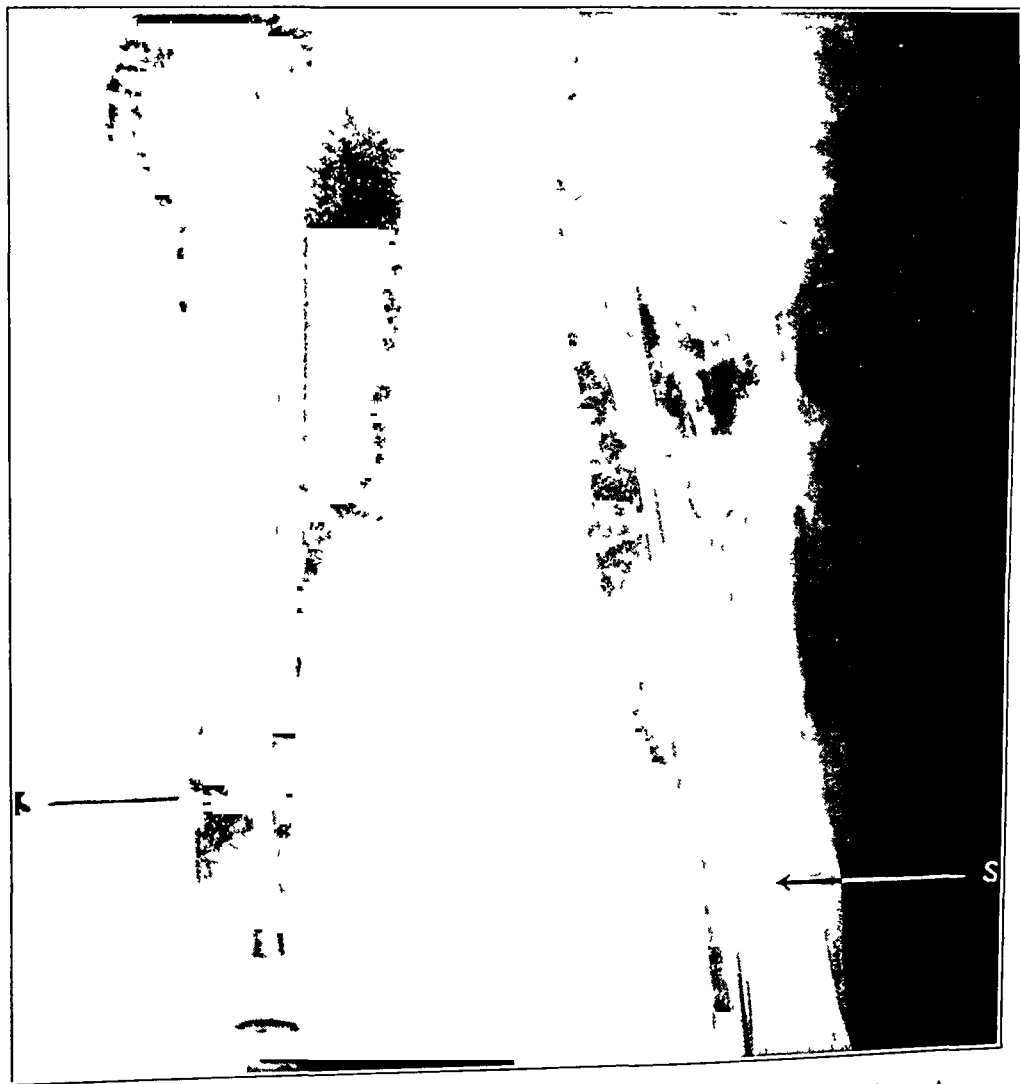


Fig 24 (Case 1)—Operation, June 22, 1919, roentgenogram taken Aug 22, 1919. S, former separation zone, marked subperiosteal proliferation. No operative procedure has been performed on this area.

It is true that in the region of the metaphysis, the bony septums somewhat resemble the septums of the mastoid, and that, therefore, in this region it may be necessary to break up the compartments of the abscess. Care should be taken even here not to traumatize any more than possible.

Constant, careful postoperative observation of these cases is necessary, as there are frequent secondary metastatic abscesses in the soft parts

*Subacute Stage*—Before the days of wound sterilization, the course of a case could be fairly definitely prophesied. At the primary operation, the shaft was opened wide, frequently curetted and packed. Following this, sequestration occurred, frequently involving almost the entire shaft. As advised by Nichols, of Boston, the sequestrum was usually removed at a time when the involucrum was strong enough to

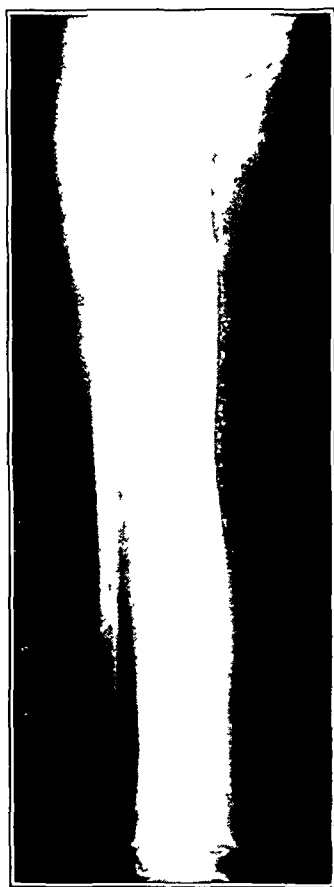


Fig 25 (Case 1) —Operation, June 22, 1919, roentgenogram taken, Nov 24, 1920, no sinus, patient apparently well

maintain the shape of the limb, and yet, at such a stage when the involucrum could be inverted, obliterating, as far as possible, the “dead space”

In 1919, I attempted to reproduce osteomyelitis in dogs before the students of the third-year course in regional surgery at Columbia. At the suggestion of Dr William C Clarke of the department of surgery, through a drill hole in the cortex of the medullary canal of the humerus,

croton oil was introduced in glass capillary tube containers having their ends sealed with agar-agar. The hole in the cortex was then plugged with bone wax, and the soft parts and the skin were sutured. By this procedure, repair following the operative trauma was allowed to progress before the croton oil was liberated from the capillary tube, probably by the solvent action of the cells and body fluids upon the agar-agar. As croton oil causes marked necrosis of the surrounding bone, we were able to produce a chemical osteomyelitis. A sequestrum,

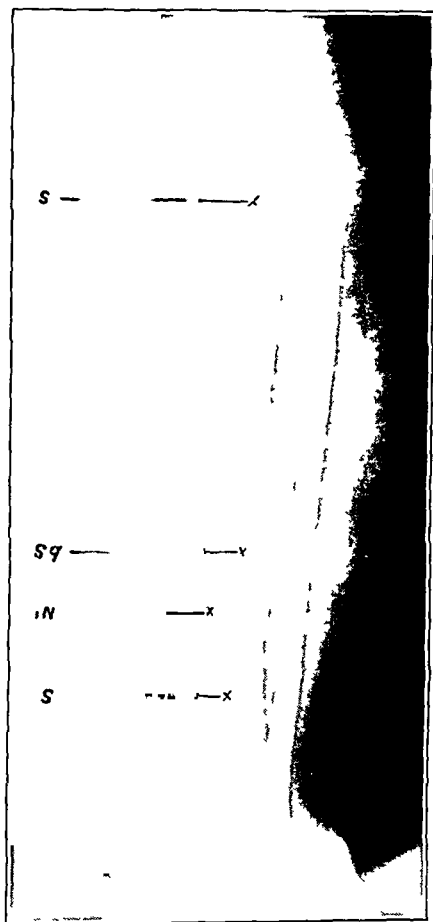


Fig. 26 (Case 2) —Roentgenogram taken, Dec. 8, 1919, previous to operation. *Sq*, sequestrum, *In*, involucrum, *S*, separation zone.

often from 5 to 10 cm. in length, and including the entire circumference of the shaft, frequently occurred (Figs 11 to 17). This sequestrum was separated from a newly formed involucrum by a zone of debris and leukocytes, therefore, all the factors of an acute osteomyelitis were present with the exception probably of bacteria and their by-products. Sections showed the sequestrum with an involucrum surrounding it but separated from it by a zone of pus. The cortical bone of sequestrum showed absence of nuclei, and throughout its cancellous portion there

was a marked infiltration of leukocytes. The involucrum consisted of newly formed subperiosteal bone.

In the prolonged animal experiments roentgenologic studies showed the gradual disappearance of the sequestrum so that at the end of two months it was impossible to detect its former outlines by the roentgen ray (Figs 18 to 22). Microscopic sections taken at this time showed the disappearance of the zone of separation, and the former sequestrum was then united to the living bone by blood vessels entering the

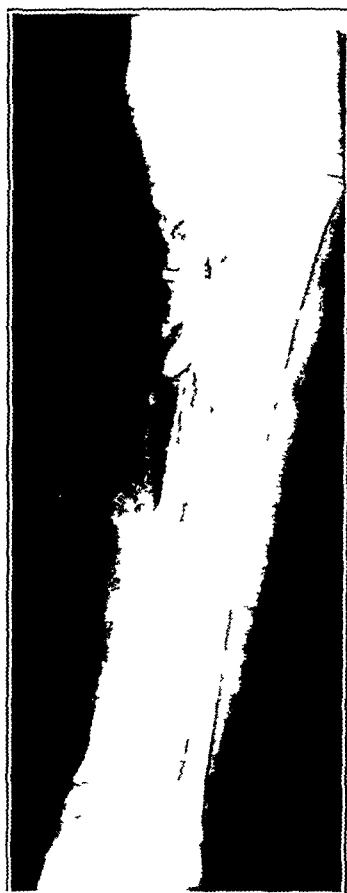


Fig 27 (Case 2)—Roentgenogram taken, Feb 7, 1920, operation, Dec 9, 1919. anterior surface of the cortex of the tibia removed, drainage tube in popliteal space shown.

haversian canals. The process was similar to that found in any bone transplant, gradual absorption and deposition of new bone occurring throughout the haversian canals until all the dead bone had been replaced.

I have emphasized these facts because I believe they have a definite influence on human surgery. I shall show in the study of clinical cases that in children bone tissues that are apparently dead can be saved to advantage.

Since the introduction of the Carrel-Dakin technic, we have had results on Dr Pool's service at the New York Hospital which correspond to a certain degree with results found in our experimental work. The following two cases show marked regeneration of bone which on either roentgen-ray or gross examination appeared necrotic.



Fig. 28 (Case 2) —Roentgenogram taken, April 10, 1920, new bone proliferation about and incorporating former dead shaft

On account of limited time, brief summaries of only two illustrative cases will be given.

#### REPORT OF CASES

CASE 1 (Figs 23, 24 and 25) —A girl, aged 5 years, came into the hospital with an acute osteomyelitis involving the upper third of the tibia. Drainage was established by removing the anterior part of the cortex in the upper

third Later, the roentgen ray revealed a marked rarefaction and apparent sequestrum formation in the lower third As the temperature was approaching normal, and her condition was quite satisfactory, it was considered advisable to delay operation on the lower third Later the roentgen ray revealed subperiosteal bone proliferation around this zone of separation, and a roentgenogram one year later revealed a relatively normal appearing shaft At the present time, she is well, without any sinus, and apparently the process is cured

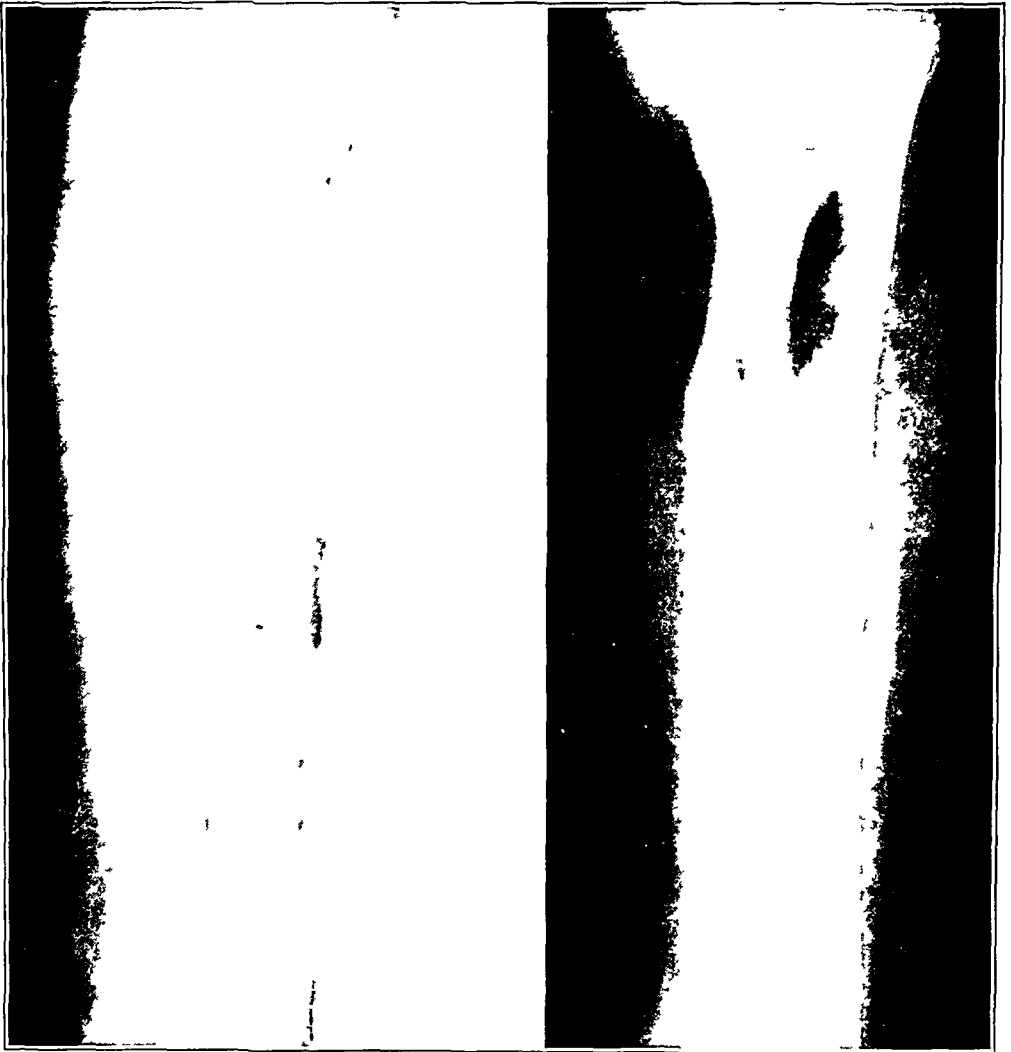


Fig 29 (Case 2) —Roentgenogram taken, Oct 18, 1920, new bone formation, wound healed, patient walking on leg, feels well

*Comment*—Primary roentgenographic studies of this patient disclosed the appearance of rarefaction and sequestration in the lower third of the tibia This completely disappeared without any operative interference

CASE 2 (Figs 26 to 29)—A boy, aged 7 years, in whom the tibia had been insufficiently drained, elsewhere, for an acute osteomyelitis, came into the hospital extremely ill, with a temperature of 106 F, marked leukocytosis and



prostration At the primary operation, the entire anterior portion of the cortex of the tibia was removed There was a fracture of the upper third due to the complete destruction of the bone Periosteum was separated by pus from the greater part of the shaft In this case Carrel tubes were inserted posteriorly between the necrotic shaft and the periosteum The shaft appeared dead It was not removed because it was thought advisable to maintain this portion of the shaft to prevent deformity After about five weeks, granulations were seen springing up on the surface of the formerly necrotic shaft Roentgenograms taken two months after the primary operation showed new bone formation about, and apparently incorporating, the remnant of the old necrotic shaft At the present time, the patient has no sinus and the roentgen ray revealed marked new bone proliferation without the sign of any sequestrum

*Comment*—This patient, who was too sick to stand any operative procedure, had a dead shaft exposed in the wound After Dakinization, granulation tissue appeared on the former necrotic surface The bone was later incorporated and the new bone formed about it Whether or not in this case the sequestrum was sterilized by the Dakin solution, it is difficult to state, but it appears that it acted very much as did the chemical sequestrum produced by croton oil injections in the experimental laboratory

#### CONCLUSIONS

From the experience obtained with these cases and from the many animal experiments, I am convinced that, in the future in the treatment of children, we can be more conservative

First, adequate drainage should be obtained with as little trauma as possible Second, in cases in which the patient is clinically progressing favorably, bone, which by roentgen-ray or gross examination, appears dead, may frequently be saved to advantage in order to prevent deformity and hasten convalescence

Finally, I believe that in the past we have made bone repair appear much too complex We have been lost in the by-ways of periosteum, endosteum and bone reticulum It is much simpler to believe that bone occurs as a chemical deposition in connective tissue Such a theory allows for bone formation as it appears in all parts of the body

In bone transplants, we must assume that the transplant per se does not live but that it acts as a framework for new bone and stimulates osteogenesis We must, therefore, apply grafts that can easily have a blood supply established, and have sufficient free surface to stimulate bone production

In the treatment of fractures, care must be taken to increase the blood supply This is more important than immobilization that constricts the limb Early motion favors union for this reason

What we are apparently doing when a bone graft is made or when extraskeletal bone occurs in an experiment is producing the right chemical state Then the process of bone formation inevitably follows

Until the physical chemist tells us more of the intricacies of the chemistry of the tissues, the practical surgeon should study the circumstances of bone production, that is, what factors promote its formation. He should not let the disputes of the various experimenters over terms, or the question as to whether this or that tissue produces bone, confuse the issue. The issue requires that the patients be cured, following injury or infection of the bony structures.

100 East Sixty-Sixth Street

# LIPPING FRACTURE OF LOWER ARTICULAR END OF TIBIA

B F LOUNSBURY, M D, AND A R METZ, M D

CHICAGO

Lipping fractures of the tibia merit consideration as a separate entity because of the difficulty of maintaining reduction and the high degree of disability accompanying union in malposition

There are two types of these fractures, the anterior and the posterior. There may be an accompanying fracture of the internal malleolus or lower end of the fibula or both, with displacement of the astragalus and foot forward or backward. In the young, there may be a separation of the epiphysis, with lipping fracture of the diaphysis.

## CAUSES

The anterior fracture is caused by a sudden violent overflexion of the foot. This might occur when the weight of the body is unexpectedly thrown on the ball of the foot, as, when in stepping up onto a curb or stair, the foot slips off and is forced upward. The astragalus is forced forward and upward. Its convex anterior articulation meets resistance against the concave anterior lip of the lower articular end of the tibia. An oblique fracture may result, displacing the anterior lip of the tibia forward and upward. The concave socket which has helped to hold the astragalus in position is then broken and this fragment, together with the foot, slides forward from under the end of the tibia. The convex posterior facet of the astragalus lies against the fractured front of the tibia.

Fracture of the posterior lip is caused by catching the heel, often on a door-sill or edge of a step or curb. The ball of the foot is without support and the foot is hyperextended. The weight of the body is thrown on the foot and tends to increase this hyperextension. The posterior lip of the tibial articulation is forced against the posterior aspect of the astragalus and a fracture, from below upward and obliquely backward, results. The posterior lip of the tibial articulation goes backward and upward, and with it the astragalus and foot. The tibial fragment may be small or large. It may be a mere tearing away of the rim, to which the joint capsule is attached, or it may involve the articular surface of the tibia to the apex of its concavity. The anterior side of the astragalus rests against the posterior fractured surface of the tibia. The joint capsule may be ruptured and the tibio-astragalar ligament torn. Frequently, the periosteum is stripped up for some distance on the back of the tibia and is attached to the small fragment.

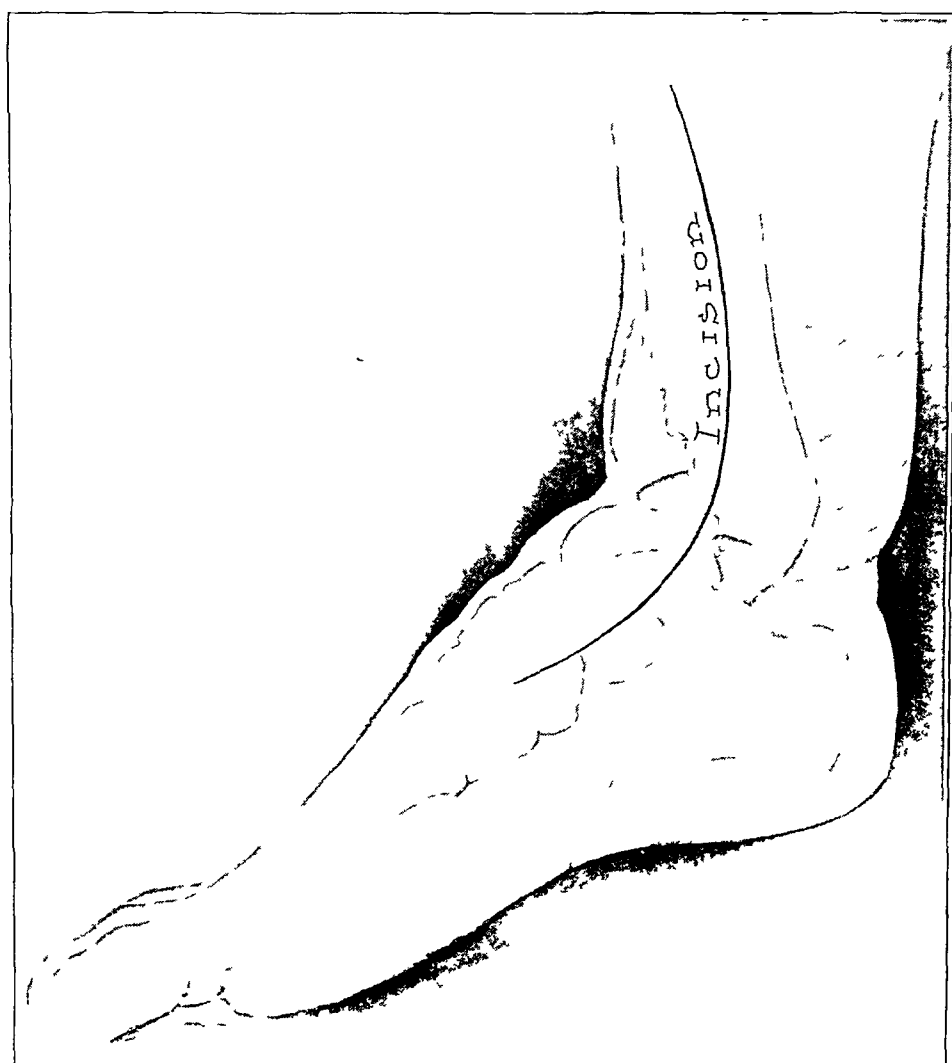


Fig 1—Deformity and skin incision in fracture of the anterior lip



Fig 2—Periosteum opened, showing forwardly displaced fragment

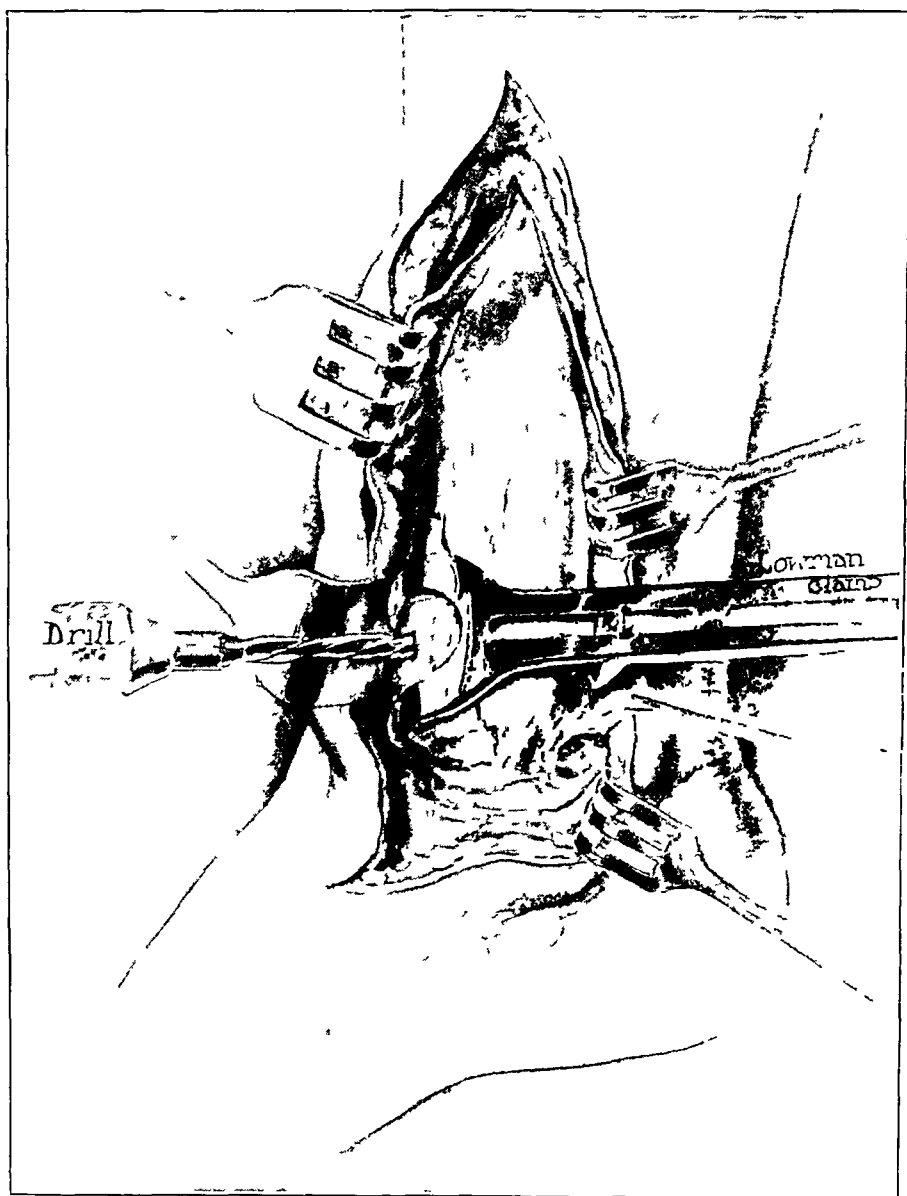


Fig 3—Fragment replaced and held with bone clamp while drill hole is being made

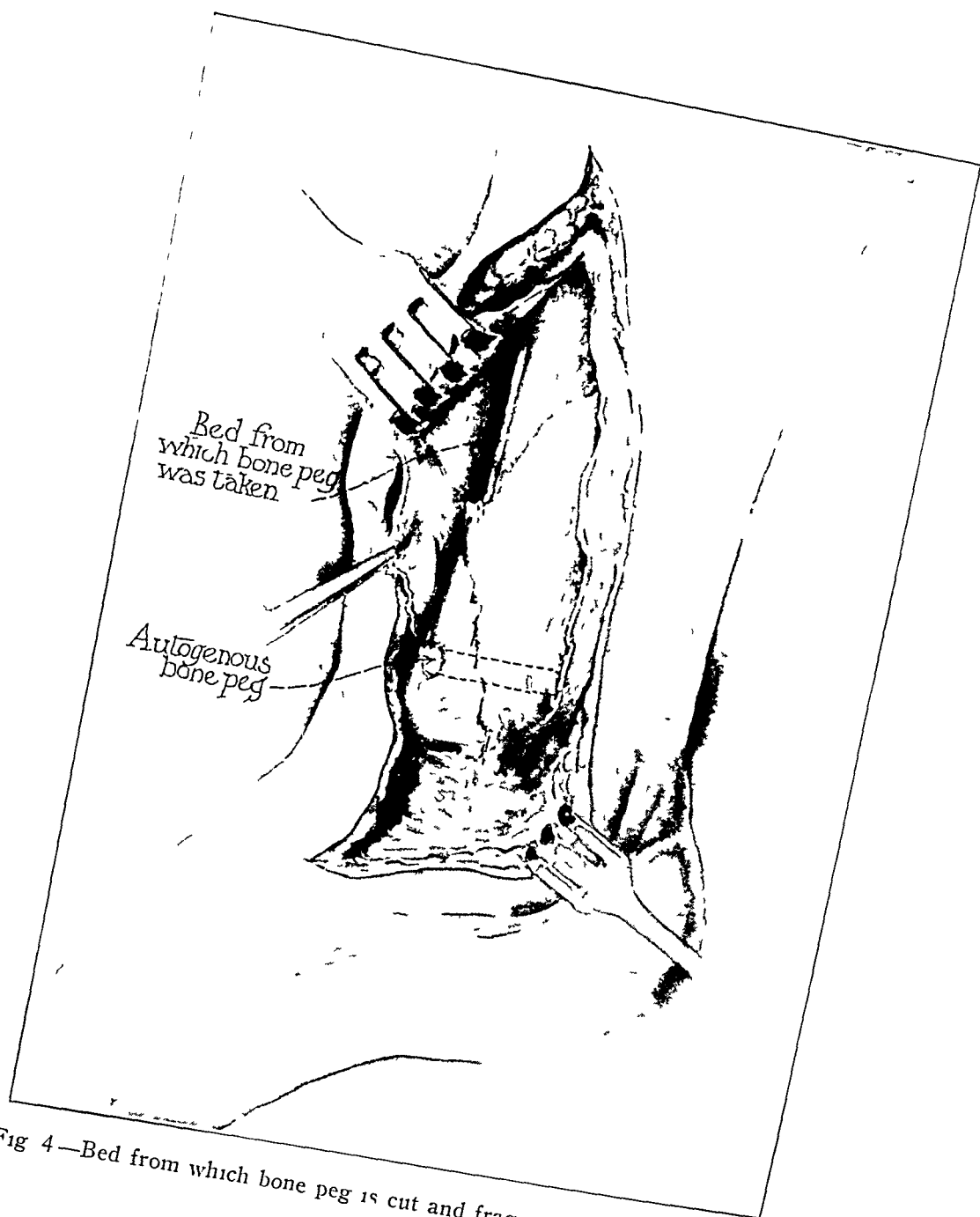


Fig 4—Bed from which bone peg is cut and fragments held by bone peg

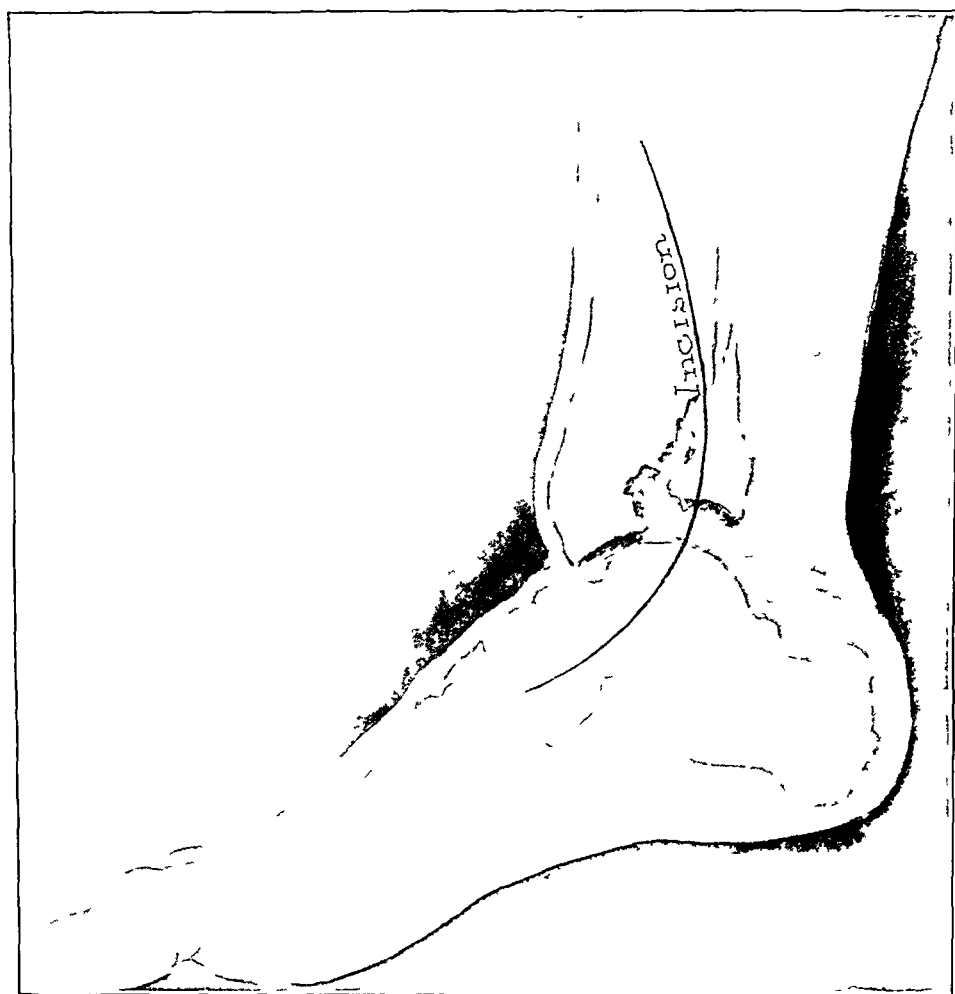


Fig 5—Posterior fracture of the tibia and displacement backward of the astragalus and foot, showing line of incision



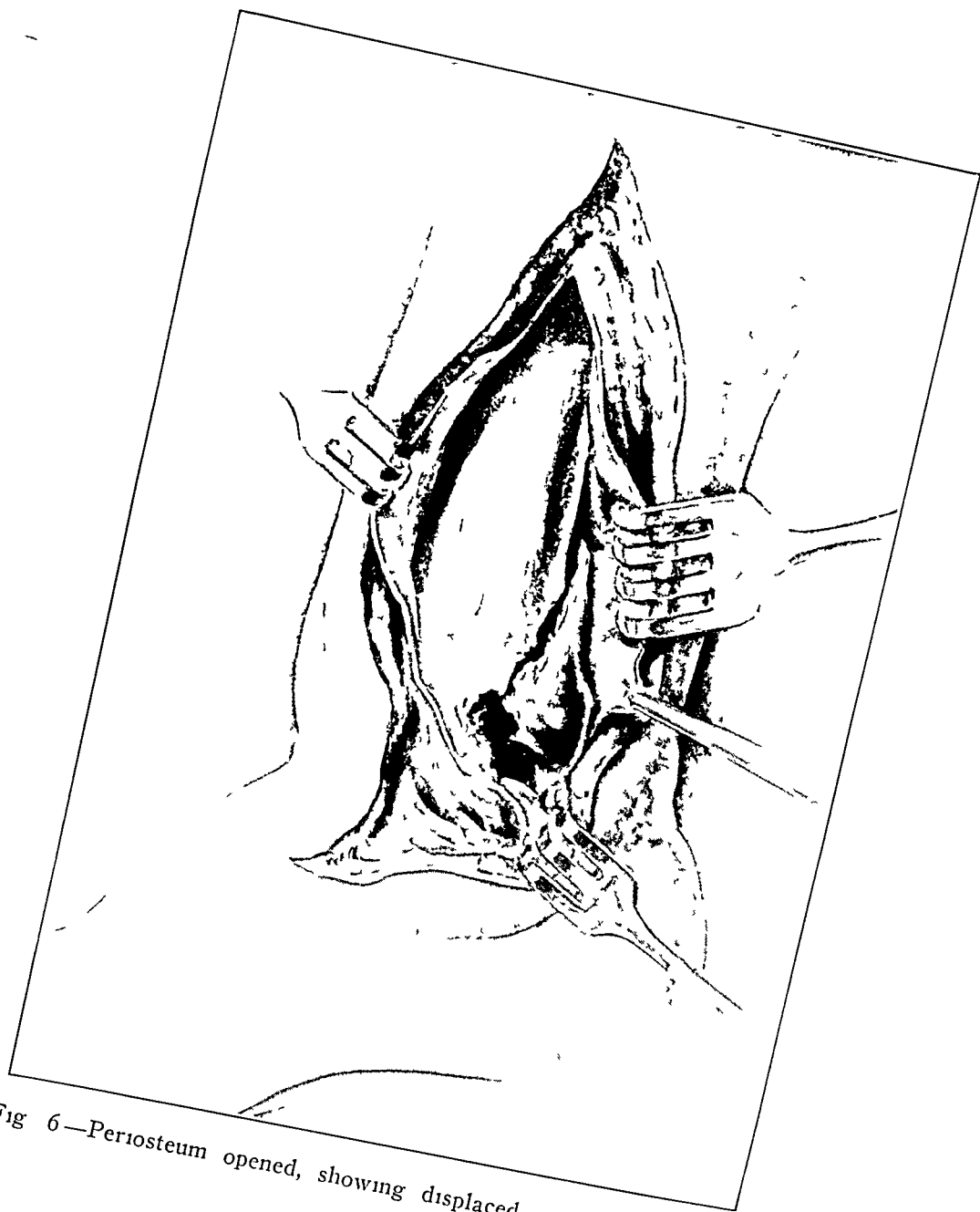


Fig 6—Periosteum opened, showing displaced posterior fragment

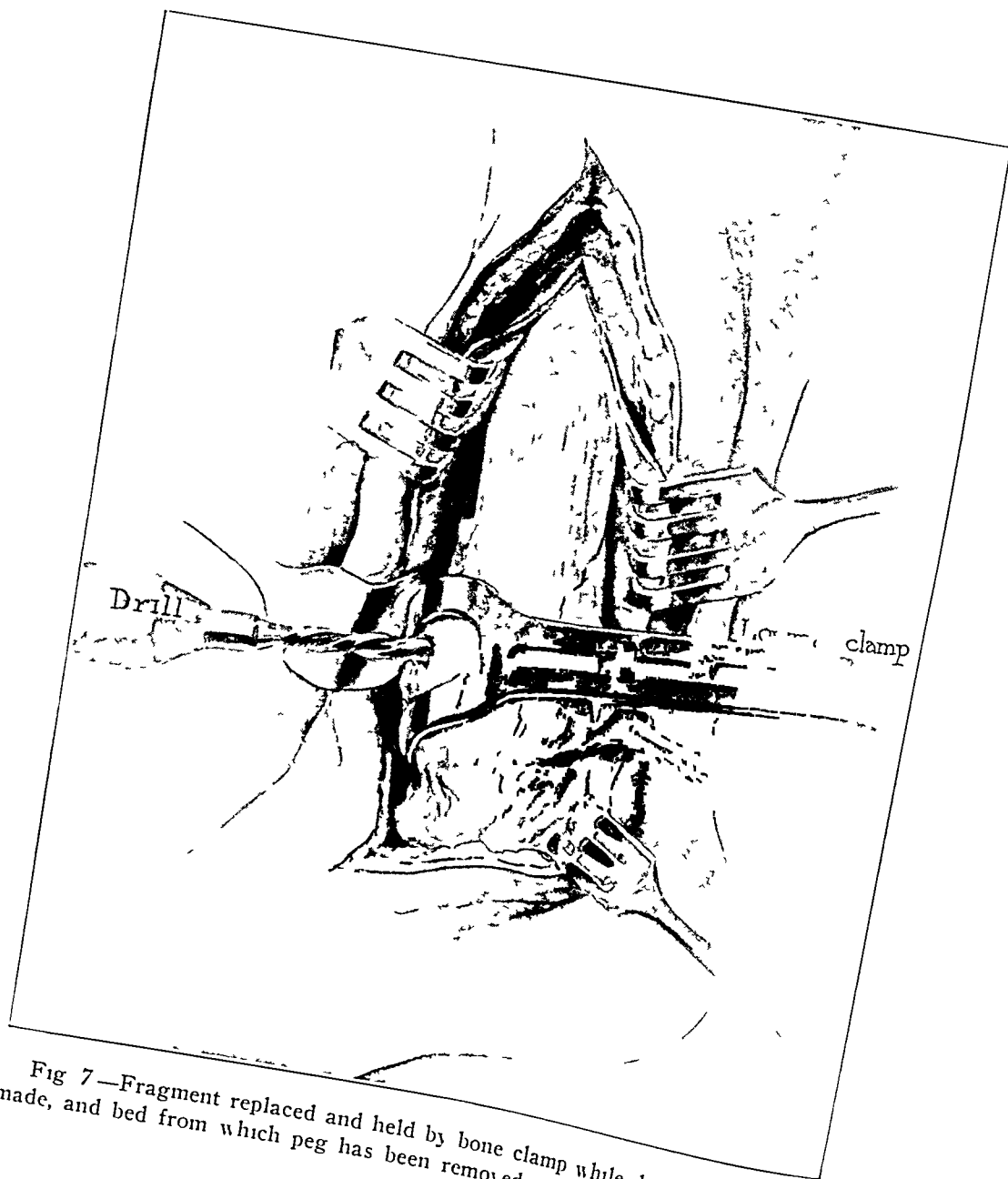


Fig 7—Fragment replaced and held by bone clamp while drill hole is being made, and bed from which peg has been removed

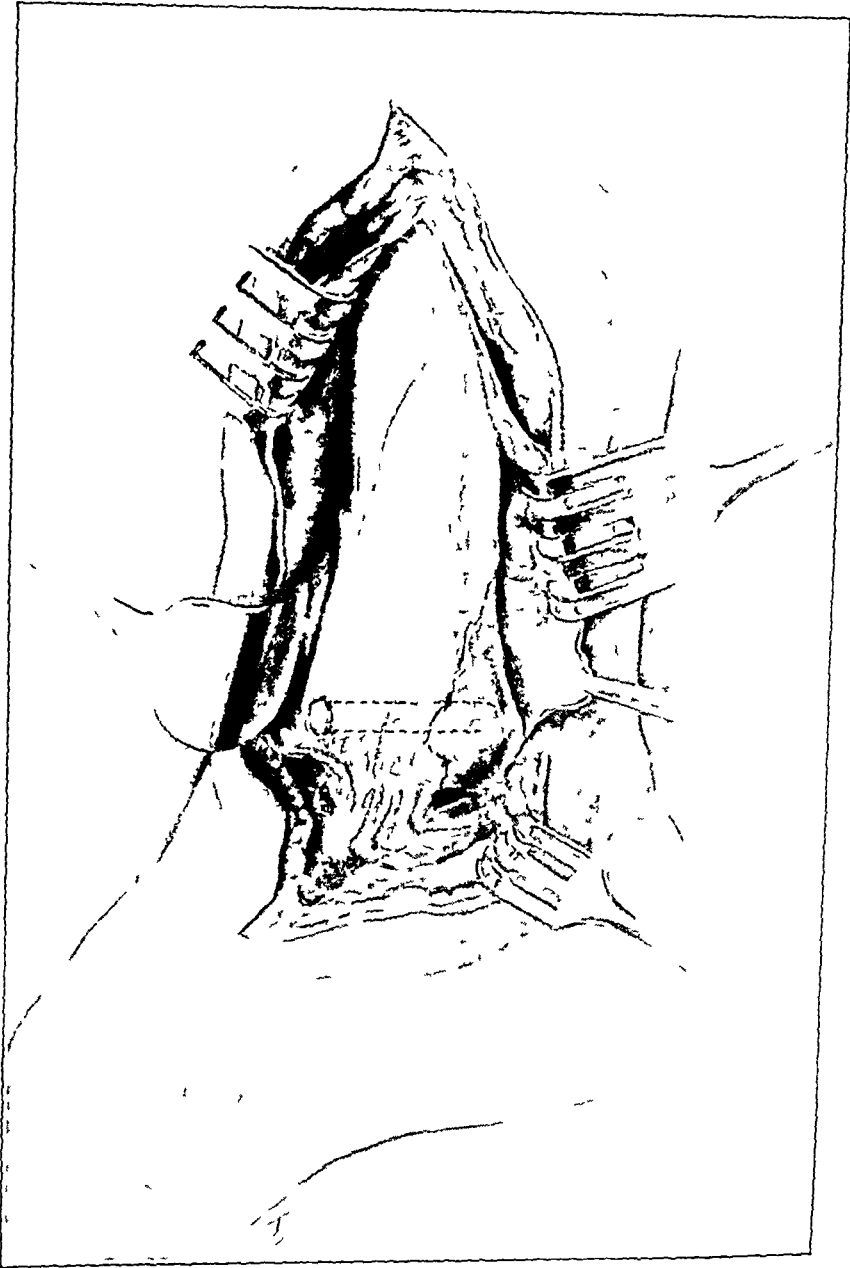


Fig 8—Posterior fragment held to the anterior fragment by bone peg

The internal malleolus may be fractured and displaced medially and upward. This may complicate either the anterior or posterior type.

The nearer the line of fracture is to the apex of the concavity of the tibial articulation, the easier it will be to reduce the astragalus and the more difficult it will be to maintain it after reduction. Frequently, the surgeon has made an excellent reduction of such a fracture and applied



Fig 9—Fracture of posterior lip of the tibia complicated by fracture of the lower end of the fibula, fourteen weeks after injury. Foot and astragalus displaced backward and held in malposition by firm callus.

a cast to maintain it. When checking the result with a roentgenogram, he has been disappointed to find that displacement has recurred within the cast, and in spite of repeated efforts of nonoperative methods, he has been unable to hold the fragments in their normal position. Under these circumstances, an open reduction and fixation of the fragments is the only method that will be effective.

## TECHNIC

Because of the complex anatomy of the ankle, open reduction of this fracture has always been difficult, especially in old cases. To simplify the operative procedures, we have developed the technic illustrated in the accompanying sketches. An incision over the medial surface of the tibia, from a point 6 inches (15 cm) above the internal malleolus, is carried down over the malleolus and curved slightly forward to the distal end of the astragalus. The incision extends down through the periosteum to the end of the tibia. The periosteum is



Fig 10—Same leg as that shown in Figure 9 after cutting callus and reducing fracture and dislocation, and maintaining reduction by autogenous bone peg cut from tibia by authors' method

reflected back from the medial surface, over the crest and over the dorsal aspect. This lays bare the fracture field in either an anterior or posterior displacement. Some shreds of periosteum or ligament may be found between the fragments. These are removed and the small fragment easily pushed into position. It is held to the large fragment by a Lowman clamp. In an anterior displacement a hole is

drilled through the small fragment into the large one, while the clamp holds them firmly. With a chisel, a peg is cut from the exposed crest of the tibia. The peg may be sharpened with ordinary bone cutters or chisel, and is then driven through the small fragment into the large one. In the posterior dislocation, the drill hole extends through the large fragment into the small one, because of easier access, and the peg, also driven from in front, passes through the large fragment into the

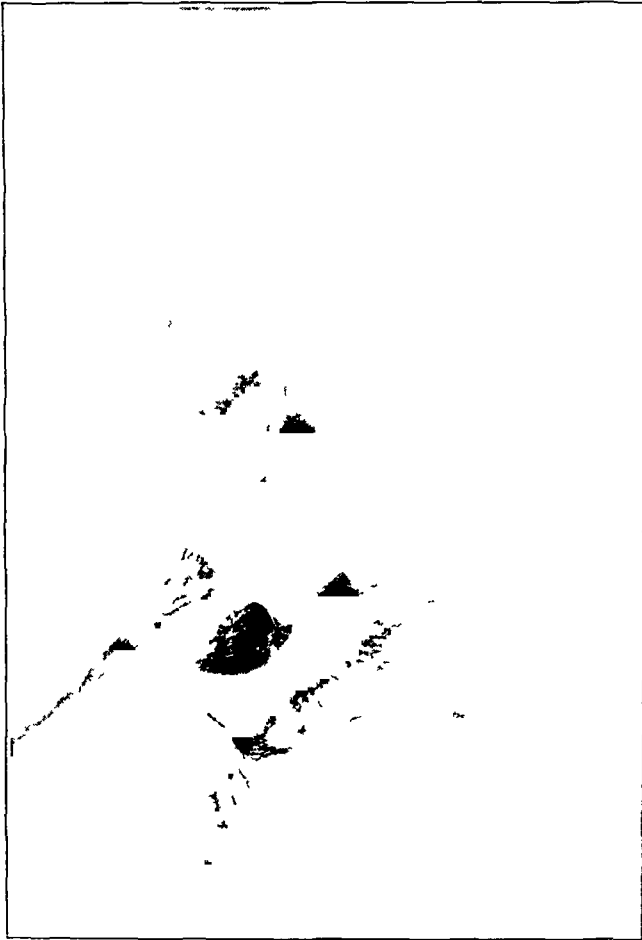


Fig 11—Separation of the epiphysis and lipping fracture of the diaphysis

small one. The peg is cut flush with the bone and the periosteum sutured. The skin is sutured with catgut and a cast applied. The cast should run to the knee and hold the foot at a right angle to the tibia. In from six to eight weeks, the cast can usually be removed and hydrotherapy and massage instituted.

In old cases in which union has taken place in malposition the problem is more difficult and necessitates the cutting of callus. Fre-

quently, the lower end of the fibula has been fractured and displaced backward or forward with the astragalus. Under these circumstances, it is necessary to cut the fibula in order to get the astragalus into its normal position. With the lip of the tibia securely pegged, it is not necessary to fix the fibular fragment, the cast answering the purpose fully.



Fig. 12—Same leg as that shown in Figure 11 after reduction and pegging with autogenous bone.

#### ADVANTAGES OF OPERATION

This operation has two distinct advantages. First, by keeping within the periosteum, the tendons may be retracted with their sheaths and the vessels displaced without fear of hemorrhage, second, the autogenous bone peg is easily secured within the field of operation by a few chisel strokes. This makes a firm fixation material with the least likelihood of unfavorable bone reaction.

# OSTEO-ARTHRITIC PROTRUSION OF THE ACETABULUM (INTRAPELVIC PFANNENVORWOLBUNG)

ARTHUR E. HERTZLER, M.D.

HALSTEAD, KAN.

Under this head, an affection of the hip joint has been described which is characterized, anatomically, by a deepening of the acetabular cavity, due to a displacement, medially, of its inner wall, and, clinically, by pain and limitation of abduction and sometimes of adduction and of rotation. It was first described by Otto<sup>1</sup>. It is a rare condition. Valentin and Muller<sup>2</sup> were able to collect only thirty-one cases, to which they added three of their own.

This condition, as described in the literature, is due to a variety of causes. I am able to present fairly well marked examples of most of the varieties.

**CASE 1—History**—A man, aged 29, complained of pain in both hip joints, which he first noticed ten years previously. It began without known cause or antecedent disease except joint pains in bad weather. At first these pains involved the hands and elbows and later the knees. These joints had not bothered him in recent years. There was at no time any febrile reaction. He had not had tonsillitis, but he had had many decayed teeth, requiring extensive dental work. At the time of examination, however, there was no defect. His general health was good.

The pain in the hips began first about six years previously. It was dull in character and was located deep in the hips. It did not radiate and was never sharp. These pains were more marked in cold, rainy weather. The same kind of pain was present at this time, but the tendency to be worse under certain weather conditions was less marked now than it had been for several years. The pain was most pronounced when he first began to walk after sitting for a time, but lessened with exercise only to increase again if the exercise was prolonged. This had recently become so marked that he had become incapacitated for all work on the farm. After exercising for a time, the muscles about the hips seemed to become stiff, making movements slow and difficult. He had noticed, a number of years previously, that it was no longer possible for him to ride horseback.

**Examination**—The physical examination revealed an apparently vigorous young man. The head and trunk showed no deviation from the normal. The musculature about the hips seemed flabby and slightly atrophic compared with the general appearance of vigor of the upper part of the body. The examination of the legs revealed a degree of flabbiness when compared with the arms.

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1 Otto. Pfannenbeckenmissgestaltung infolge deformierender Osteoarthritis. Seltene Beobachtungen zur Anatomie, Physiologie und Pathologie gehörig, Ed. 2, Berlin 1824.

2 Valentin, B. and Muller, H. Intrapelvine Pfannenvorwölbung (Pelvis Otto-Chrobak), Arch. f. klin. Chir. **117** 523, 1921.



Both trochanters projected a finger's breadth or more about the Nelaton line. External rotation was distinctly limited, as was also internal rotation to a lesser degree. Abduction was possible only to a very limited extent, not more than 20 degrees, and the attempt to force it caused pain. Adduction was somewhat limited but less so than abduction. Flexion was possible to a right



Fig 1 (Case 1) —Right hip, showing normal angle of the neck and shaft. The great trochanter lies less than a centimeter from the acetabular brim. The floor of the acetabulum protrudes into the pelvis. The joint surfaces are unaffected and the bone forming the floor of the acetabulum is not changed nor thickened. There is slight lipping of the lower border of the acetabulum.

angle. Within these ranges, the movement was free and painless and without any sensation of friction.

The roentgen ray demonstrated the great trochanters closer to the acetabular rim than normal (Figs 1 and 2). The acetabulum was free from lipping

or other evidence of disease except at the lower border. The angle of the neck of the femur with the shaft was apparently approximately normal. The striking feature noted in the roentgenogram was that the acetabulum protruded toward the pelvic cavity, deepening it to a marked degree. The acetabular floor was not thickened and the surface it presented toward the pelvic

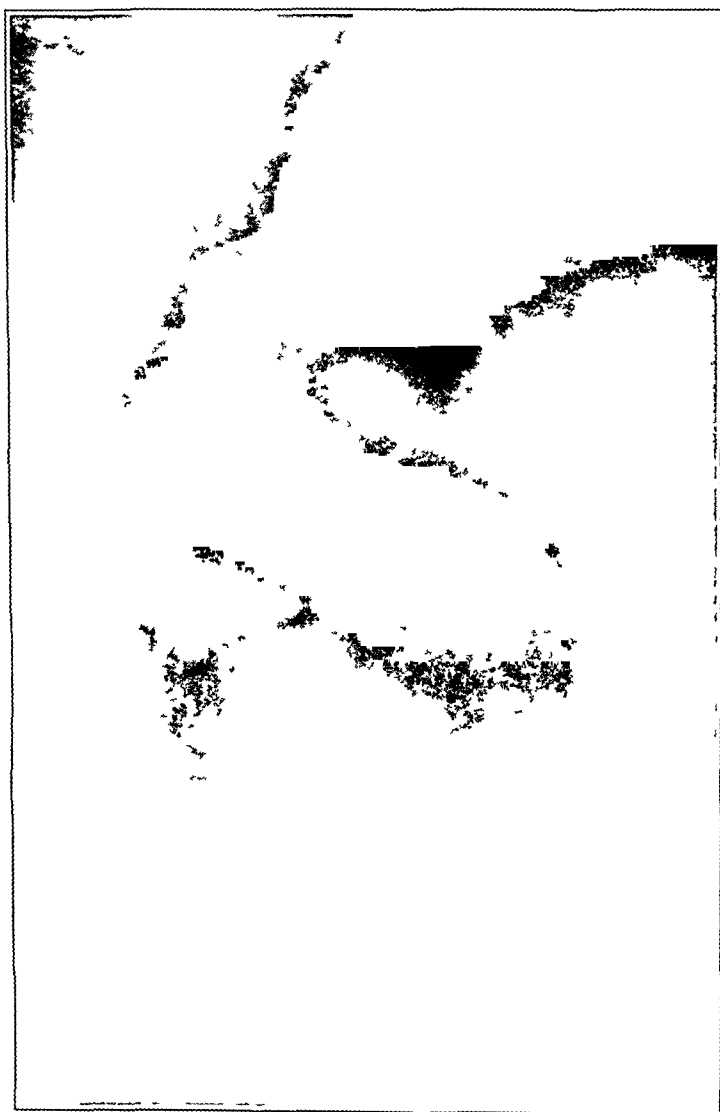


Fig 2 (Case 1) —Left hip of the same patient

cavity was smooth in outline. There was no evidence of disease of the femur nor of the pelvic bones. On rectal examination the protrusion was more striking than it appeared in the roentgenogram. The sensation was as though half a billiard ball had been cemented over each acetabular region.

*Diagnosis*—The slight limitation of external rotation and the marked limitation of abduction at once suggested coxa vara, but the lack of marked limitation of internal rotation made this diagnosis doubtful. The roentgen ray

showed no marked change of the angle of the neck of the femur, but did show a deepening of the acetabulum. The lipping of the lower border of the acetabulum suggested an inflammatory process.

*CASE 2—History*—A woman, aged 44, complained of pain in the left thigh and hip. She had been a strong and healthy child until the age of 6, when she sustained a slight injury of the left hip. She was confined to bed with continuous pain and fever. A sinus formed but in six months she was able to get about on crutches. The sinus did not heal for nearly eight years.

She had been able to walk with crutches until six months previously, when she injured her hip slightly. She walked about for a week following the injury, but had not attempted to do so since.

*Examination*—There was marked limitation of motion in all directions. Abduction was altogether impossible, as was external rotation. The roentgen

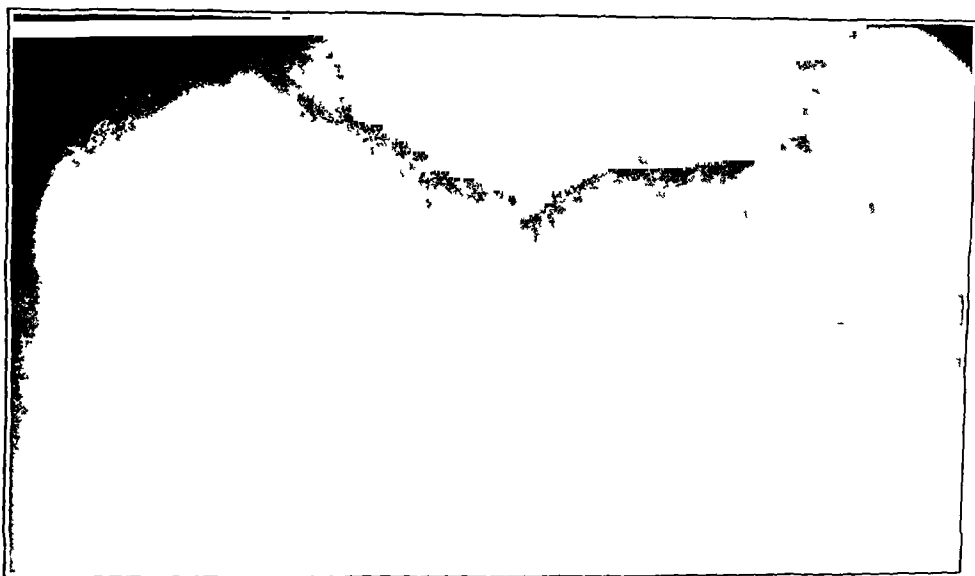


Fig 3—The entire lateral border is displaced markedly medially, protruding into the pelvis more than a third of its diameter. There is thickening of the bone which forms the floor of the acetabulum. The head of the femur is deformed and the neck and shaft of the femur are atrophied and rarefied.

ray revealed the whole acetabular cavity displaced markedly medially (Fig 3). The acetabulum was deepened and there were marked changes in the acetabular border and in the neck and head of the femur. In fact, the roentgen ray would indicate a bony ankylosis, an impression heightened by the marked atrophic changes in the femoral shaft and head.

*Diagnosis*—The marked median displacement of the entire acetabular cavity constituted the sole reason for including this case in this category. Esau<sup>3</sup> reports a case of this type. The clinical findings do not correspond to the true Otto type, so they will be referred to again later.

<sup>3</sup> Esau, P. Akute Osteomyelitis des rechten Schamborns und zentrale pathologische Luxation des Oberschenkels, Deutsch Ztschr f Chir **91** 611, 1908.

CASE 3—*History*—A woman, aged 36, came for examination to determine whether an old hip disease would make childbirth hazardous. When 5 years old, she began to have pain in the left hip and knee. She was treated for several years with a hip splint. The pain ceased, but there was limitation of

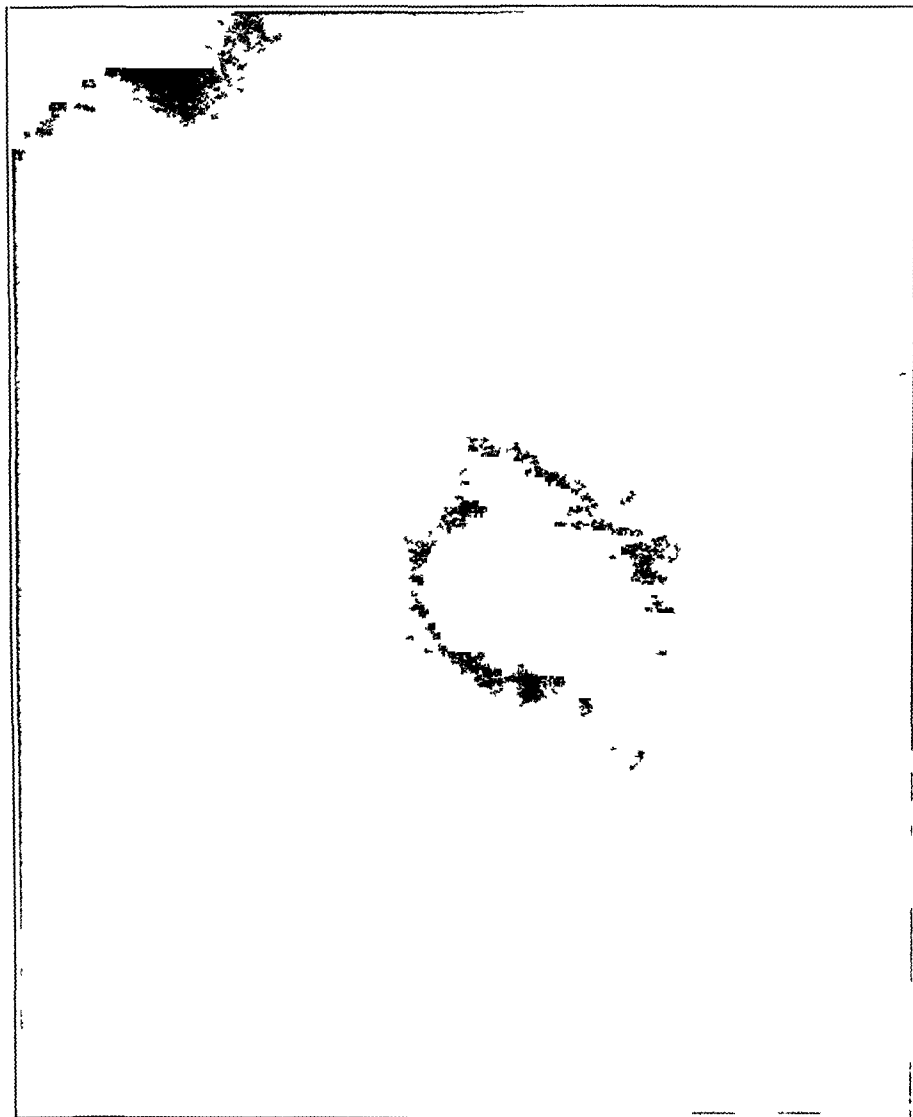


Fig. 4—Old tuberculous disease of the hip. There are marked trophic changes in the head and shaft of the femur. The acetabular protrusion is due to a thickening of the bone rather than an actual protrusion.

motion in the hip joint. She was given an anesthetic and the joint was freely mobilized. Following this she had fever and swelling about the joint for several months, and when this subsided, she was unable to move the thigh at all.

*Examination*—There was complete fixation at the hip joint (Fig. 4). The thigh and hip regions showed marked muscular atrophy. The roentgen re-

revealed complete ankylosis. The acetabulum was deepened and protruded into the pelvis. This protrusion was more impressive when examined by the vagina and rectum than it appeared in the roentgenogram.

*Diagnosis*—The roentgen-ray findings did not correspond to those usually found in old tuberculous hip disease. However this apparently is accounted for

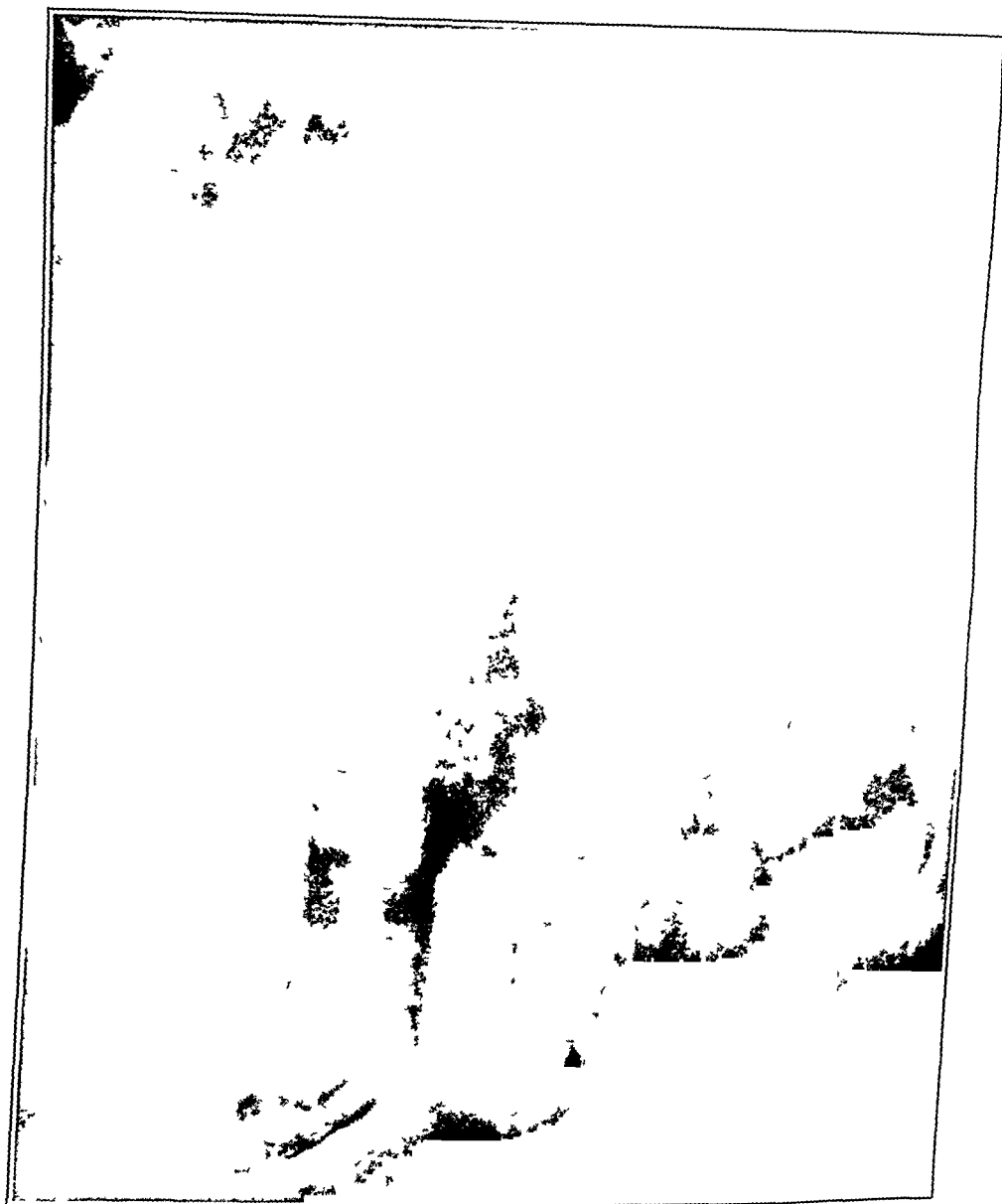


Fig 5—Extensive carcinomatous metastasis of the ischium. The floor of the acetabulum shows thickening and some displacement.

by the marked inflammatory reaction following the manipulation under ether at a time when the original disease was in abeyance.

CASE 4—A woman, aged 46, was brought to the hospital because of pain in the back. The details of the history and findings in this patient are of no interest here. She had had one breast removed by a caustic paste two years before, followed a year and a half later by pain in the back. The roentgen

ray revealed many metastatic nodules. It is of interest to note that the metastases in the ischium had permitted a protrusion toward the median line (Fig 5). The picture is shown here because a similar condition was presented by Thomsen<sup>4</sup> as a type of osteo-arthritic protrusion of the acetabulum.

## COMMENT

Case 1, here presented, seems to belong to a condition wherein the disability is due to the deepening of the acetabular socket, as already noted. It was first described by Otto<sup>1</sup>. As indicated by the title of Otto's paper he considered an inflammatory reaction the causative factor. In several of the cases reported, mild inflammatory reactions have preceded the deformity. Thus Wolfsohn and Brandenstein<sup>5</sup> report a case in a man, aged 36, who had a rather typical inflammatory rheumatism five years before. Gradually the movements in the hip joint became limited and a protrusion of the acetabular cavity followed. Schertlin<sup>6</sup> and Henschen<sup>7</sup> report similar instances. It is to this type that my Case 1 belongs. Most cases recorded apparently follow a coxitis of a relatively mild degree. The general term juvenile osteo-arthritis seems, as suggested by Wolfsohn and Brandenstein,<sup>5</sup> to be descriptive, except that in the majority of cases recorded the dominant symptoms appeared too late in life to be "juvenile," it is possible, however, that the first changes began during adolescence.

Eppinger<sup>8</sup> believes the disturbance is due to a late ossification of the bones making up the acetabular floor. According to him, the constant muscle pressure on the cartilaginous floor is sufficient to produce the condition. Other authors combat this hypothesis chiefly for the reason that a delay in ossification has not been proved, and that the cases reported give histories of a preexisting arthritis.

The significance of frank infections of the joint, particularly by pus organisms, has been emphasized by Esau<sup>3</sup>. My Case 2 belongs here. In this case, a pyogenic infection may fairly be assumed. Apparently, a disturbance of the ossification centers followed, with displacement of the horizontal ramus of the pubes. I observed a patient some years ago in whom there was frank suppuration on the right side which was

4 Thomsen. Krebsige Osteomalacie, *Arch f klin Chir* **13** 235, 1872

5 Wolfsohn and Brandenstein. Ueber Osteoarthritis coxae juvenilis duplex, *Arch f klin Chir* **96** 656, 1911

6 Schertlin. Ueber einen Fall von intrapelviner Vorwölbung und zentraler Wanderung der Hüftpfanne, *Beitr z klin Chir* **71** 406 1910

7 Henschen. Die intrapelvine Vorwölbung und die ventrale Wanderung der Hüftpfanne, *Beitr z klin Chir* **65** 599 1909, Die traumatische (spontane) Luxatio centralis femoris *Beitr z klin Chir* **62** 294, 1909. Die zentrale oder intrapelvine Pfannenwanderung der Hüfte auf coxitisch-artthropathischer Grundlage *Ztschr f orthop Chir* **33** 438 1913

8 Eppinger. Pelvis-Chrobak. Coxarthrolisthesis-Becken. *Beitr z Geburtsh u Gynak* **2** 176 1903

drained after several weeks. The left side became affected and was drained early. On this side, there is some acetabular protrusion with some changes in the bones. On the right side, the bone changes are extensive (Fig 6). It is possible that the left side in this case stands midway between the extreme suppuration as shown in the right side.



Fig 6—At the left of the roentgenogram the head of the femur and the acetabulum show extensive changes. On the right, the femur shows extensive changes, the floor of the acetabulum shows relatively slight changes but protrudes somewhat into the pelvis.

and the type Otto has shown in Figure 1. In another case, with double suppurative arthritis, there was a protrusion of the whole lateral pelvic arches (Fig 7), being a lesser presentation of the condition shown in Figure 2. In the paper of Valentin and Muller,<sup>2</sup> they seem to include such cases as of the true Otto type. The gonococcus has been accused by Henschen<sup>7</sup> and Chiari<sup>9</sup> to be the cause.

<sup>9</sup> Chiari: Ueber die Aetiologie und Pathogenese der intrapelvinen Pfannenprotrusion, Beitr z klin Chir **102**, 1916.

Tuberculous infection has been observed, notably by Chiari and by Bier. My Case 3 belongs to this group. The deformity here is not great, but it indicates the process by which the deformity develops. Trendelenburg<sup>10</sup> described one due to the echinococcus.

Tabes was diagnosed by Fere,<sup>11</sup> Wrede<sup>12</sup> and Kienbock<sup>13</sup>. In such instances, it appears to be a generalized overproduction rather than the medial displacement of the floor of the acetabulum.



Fig 7—Double suppurative arthritis in a girl, aged 10 years. These joints were both drained. The transverse diameter of the pelvis is lessened and there is some protrusion of the acetabulum. These resemble, in a mild degree, the conditions shown in Figure 3.

Displacement from invasion by tumor was first observed by Thomsen,<sup>4</sup> and this also was the causative factor noted in one of the

10 Trendelenburg. Echinococcus multilocularis der rechten Beckenhälfte, Verhandl d deutsch Gesellsch f Chir **10** 61, 1881.

11 Fere. Description de quelques pieces relatives aux lesions osseuses et articulaires des ataxiques conservees au musee anatomo-pathologique de la Salpetriere. Arch de neurol **4** 1882.

12 Wrede. Demonstration eines Tabesbeckens und eines Otto-Chrobakschen Beckens. Tr 82 Versamml deutsch Naturf u Aerzte in Königsberg 1910.

13 Kienbock. Ueber die mit Protrusion des Pfannenbodens einhergehenden Erkrankungen des Hüftgelenks und ihre Beziehungen zur Arthritis gonorrhoeica und Arthropathie bei Tabes. Fortschr a d Geb d Röntgenstrahlen **18** 280 1912.



cases reported by Senftleben<sup>14</sup> and by Valentin and Muller.<sup>2</sup> Numerous other instances have been recorded in which there was a displacement of the head of the femur inward. I had one such instance in sarcoma of the ischium and one in metastatic carcinoma from carcinoma of the breast. This is presented herewith as Case 4.

It seems doubtful whether deformities due to specific infections and to malignant growths should be admitted to this disease group. I would exclude cases due to acute osteomyelitis, tuberculosis, nerve disease and tumors. The course and pathology of these are so different from the typical cases of Otto's disease that confusion is caused by their inclusion. I would, therefore, include only about twenty of the reported cases and Case 1 of my own as typical instances of Otto-Chrobak disease. In this connection, it is not possible to speak convincingly of those associated with gonorrheal arthritis. Schlagenhauser<sup>15</sup> records one instance in which a pure culture of gonococcus was obtained from a case running an acute course. Kienbock likewise reports a case. It may be, therefore, that in some of the cases of insidious onset the gonococcus may have played a part. One cannot, therefore, exclude this etiology from the typical Otto-Chrobak disease.

Viewing the reported cases as a whole, it seems probable that a change in structure of the bone is brought about by a chronic inflammatory process. We cannot do better, therefore, than to conclude with Otto that the disease is due to an osteo-arthritis.

The diagnosis of the typical Otto type is characterized by marked limitation of abduction and external rotation, with a lesser limitation in the other movements. Flexion in Schertlin's case was limited to a third of the usual range. In my case there was slight limitation of flexion. Usually, the greater trochanter is not displaced, but in Schertlin's case there was a displacement of 3 cm. In my case there seems to be some displacement upward, but the range was not above that of personal error.

The clinical importance of this disease, aside from the limitation of motion, is that it sometimes reduces the oblique diameter of the pelvis sufficiently to make it a hindrance to delivery. Henschen<sup>7</sup> and Kuliga<sup>16</sup> have each made a study of this phase of the subject.

#### CONCLUSIONS

1 Following a chronic arthritis, there may be a protrusion of the acetabular floor into the pelvic cavity.

14 Senftleben. Ueber Fibroide und Sarkome in chirurgisch-pathologischer Beziehung. Arch. f. klin. Chir. **1** 81, 1860.

15 Schlagenhauser, F. Ueber Coxitis gonorrhoeica und ihre Beziehung zur Protrusion des Pfannenbodens, Zentralbl. f. Gynak. **30** 228, 1909.

16 Kuliga. Ueber Chrobaksches Becken, Zieglers Beitr. z. path. Anat. u. z. allg. Path. Festschr. f. Arnold, 1905.

2 This produces limitation of abduction and external rotation and some limitation of movement in other directions

3 This protrusion may shorten the oblique diameter of the pelvic outlet

4 The displacement of the acetabular floor by specific disease or tumor metastases should not be placed in the group of osteo-arthritic protrusion of the acetabulum of Otto

# RESULTS OF TREATMENT OF FRACTURED FEMURS IN CHILDREN

WITH ESPECIAL REFERENCE TO BRYANT'S OVERHEAD TRACTION \*

W H COLE, M D

ST LOUIS

This review of the cases of fractured femur encountered in the St Louis Children's Hospital was made primarily to present the method of treatment and its results in simple fractures. In addition, an analysis of the entire group of cases of fractured femur, including pathologic fractures, has been made.

## ANALYSIS OF CASES

Altogether, the reports of thirty-five cases<sup>1</sup> have been collected. Thirty-one of these were simple fractures, eighteen of which were treated by overhead traction.<sup>2</sup> Considering the ratio of ages, fracture of the femur is much more common in infancy, five of the thirty cases occurring in infants, 1 year of age or under.

Depending on the kind of fracture and the complications, six different methods of treatment have been used, viz (1) overhead traction, (2) plaster casts, (3) splints, (4) horizontal traction, (5) open reduction, and (6) modified Steinman pin.

The five cases treated by plaster cast represent almost exclusively those in which there was little or no displacement. By using a cast in the treatment of these cases, the patient is allowed to go home much earlier and without the danger of refracture. As stated, eighteen of the thirty-one cases were treated by overhead traction.

Table 3 reveals that practically one half of the thirty-one cases were transverse fractures. Almost all of the oblique fractures were treated by overhead traction. This method, however, was also used in transverse fractures. All of these five were overriding fractures. The three cases treated by open reduction were transverse fractures, two, however, with no more displacement than in those treated by overhead traction. All the cases treated by casts and splints represent almost exclusively those with very little or no displacement. Of the two patients treated by horizontal traction, one was 12½ years old.

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\* From the Department of Surgery, Washington University School of Medicine.

<sup>1</sup> This series was taken from the service of Dr Clopton of the St Louis Children's Hospital, and the work was undertaken at his suggestion.

<sup>2</sup> Bryant, Thomas. Practice of Surgery, London 2 422 1879.

TABLE 1—RATIO OF SIMPLE TO PATHOLOGIC FRACTURES

Simple—	No of Cases
Infants (1 year or under)	5
Children (1 to 12 years)	26
Pathologic—	
Osteomyelitis	2
Syphilis	1
Osteitis fibrosa cystica	1
	—
Total	35

TABLE 2—METHOD OF TREATMENT AND INFLUENCE OF AGE ON IT

Method of Treatment	No of Cases
Infants (1 year or under)—	
Overhead traction	1
Plaster cast	2
Splint	2
	—
Total	5
Children (1 to 12 years)—	
Overhead traction	16
Plaster cast	4
Horizontal traction	2
Operative reduction	3
Modified Steinman pin	1
	—
Total	26

TABLE 3—INFLUENCE OF KIND OF FRACTURE ON METHOD OF TREATMENT

Method of Treatment	No of Cases
Oblique Fractures—	
Overhead traction	13
Horizontal traction	1
Modified Steinman pin	1
	— 15
Transverse Fractures—	
Overhead traction	5
Plaster cast	5
Open reduction	3
Horizontal traction	1
Splint	1
	— 15
Greenstick — splint	1
	—
Total	31

This is perhaps two or three years beyond the upper age limit when fractures may be treated safely by the overhead method. A modified Steinman pin was used in the case of one patient who sustained a compound fracture of the tibia, infected with gas bacilli, which necessitated amputation of the entire leg.

The figures in Table 4 demonstrate quite conclusively that the kind of fracture is distinctly determined by the location, or vice versa. With one possible exception, all oblique fractures were located in the middle third. Transverse fractures in the middle third, however, are quite frequent, as indicated by a ratio of six transverse to fourteen oblique fractures.

#### APPARATUS FOR OVERHEAD TRACTION

One of the greatest advantages of overhead traction is the simplicity of traction and the relatively slight attention required. On account

TABLE 4—LOCATION OF FRACTURES

Kind of Fracture	No of Cases
Upper third—	
Transverse	3
Oblique	0
Total	<u>3</u>
Middle third—	
Transverse	6
Oblique	14
Greenstick	1
Total	<u>21</u>
Lower third—	
Transverse	6
Oblique (at junction of middle and lower third)	1
Total	<u>7</u>

of the decreasing flaccidity of the hip joint with age, the use of overhead traction is restricted, roughly, to patients below the age of 10. A decided advantage in treating fractures in infants by this method is the cleanliness and immediate relief of discomfort that it affords. We have failed, as yet, to see a form of splint or cast which, when applied to a patient under the age of 2, could be kept free from urine and feces. Moreover, children, when put up in splints, almost invariably cry and fret for many days following the fracture. I believe we have not had a single patient who did not cease fretting within twelve hours after the application of overhead traction.

The overhead method is applicable to the average child's bed or crib, since practically all of them have head and foot railings of equal height. A bar is placed horizontally from the top rail of the head piece to the top rail of the foot piece. Ordinary adhesive strips are

used for traction, and applied well up to the site of the fracture. Reinforcing strips should be applied, preferably horizontally up the leg to the line of fracture and not by circular turns, which cause constriction followed by pain and edema. A bandage is applied snugly around the extremity, not only to keep the limb warm, but also to encourage the adhesive to stick. A heavy cord is tied to the foot piece of the adhesive strip. After lifting the extremity to a right angle with the bed, the extension cord is carried to a pulley attached to the cross-bar, from there it is carried to a pulley at the foot of the bed so that the weight hangs out of the child's reach. Coaptation



Fig 1—Apparatus for overhead traction, sufficient weight is used barely to lift the buttock off the bed, one horizontal bar may be used instead of two

splints are usually applied in the beginning of the treatment because of the support given at the site of fracture if the child twists his body suddenly. The simplest splints are made by laying ordinary wooden tongue depressors on a wide adhesive strip at a distance of one-half inch (1.27 cm), and a similar adhesive strip applied to cover them. The strips should be just wide enough to allow exposure of a half-inch of the ends of the tongue depressors. This flexible splint is wrapped once around the site of fracture after a towel or bandage has been applied. Wide linen tapes with buckles are most satisfactory for holding the splint in place.

If desired, instead of using one horizontal bar, two may be laid across the top rails of the bed at a distance of about a foot apart, and the extension pulley tied to a bar connecting the two horizontal bars (Fig 1) This allows a slightly more flexible extension, though it is not at all necessary Ordinarily, the limb is held in overhead traction

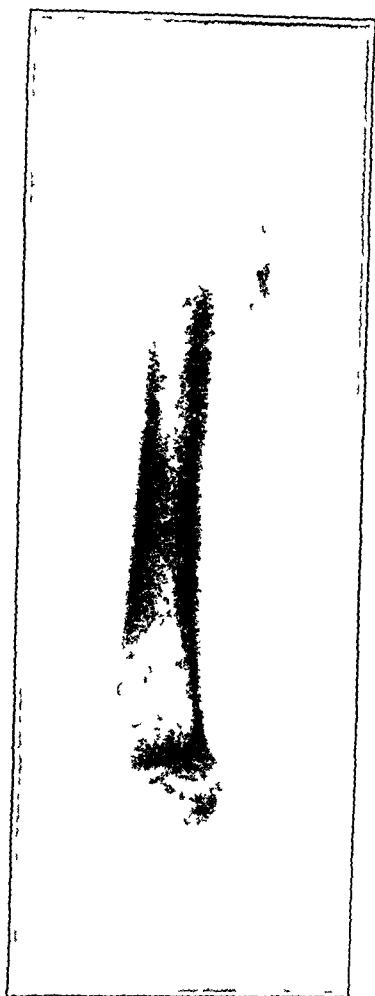


Figure 2

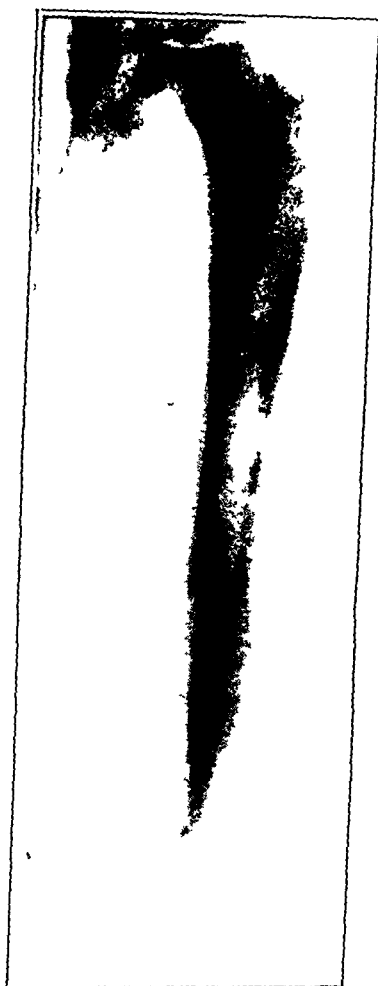


Figure 3

Fig 2—Oblique fracture of middle third of femur of patient, 4 years of age, roentgenogram taken at time of fracture

Fig 3—Same patient as in Figure 2, one and one-half years after fracture, overhead traction used

for from three and one-half to four weeks At the end of this time, a plaster cast is applied, and at the end of five and one-half or six weeks, the patient is discharged The cast need be worn only two or three weeks

This method of treatment, or ones similar, is quite commonly used and has been practiced for thirty-five or forty years Very few

reports concerning it, however, are found in the literature. It is mentioned by McCosh,<sup>3</sup> in 1897, as a practical means of treating fractures in children, but no cases are cited. Sterns<sup>4</sup> of Cleveland used it in infants in 1905, with very successful results. A simple modification has been suggested by Silver,<sup>5</sup> consisting in attaching a vertical bar

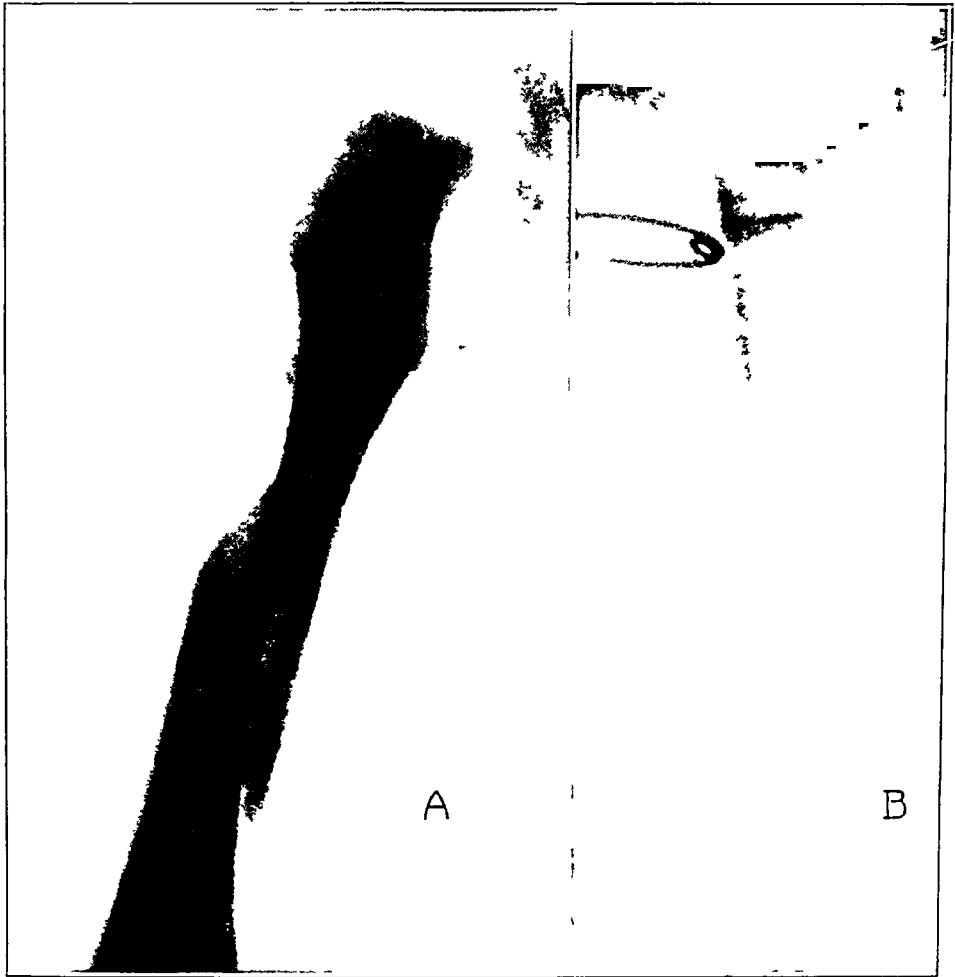


Fig 4—*A*, oblique fracture of middle third of femur of patient, 2 years of age, roentgenogram taken at time of fracture, *B*, appearance of femur two weeks after fracture and application of overhead traction

to a Bradford frame. Mention of overhead traction is found in a few of the textbooks<sup>6</sup> on surgery, but no very extensive description

3 McCosh. *Ann Surg* 26 368 1897

4 Sterns. *New York M J* 81 992-994 1905

5 Silver. *Ann Surg* 49 105-106 1909

6 Warbasse. *J P. Surgical Treatment Philadelphia* W. B. Saunders Company 1 590 1919. Stimson. *L. A. Fractures and Dislocations, Philadelphia Lea & Febiger* 1910 p 408



of results is given. Various methods of operative reduction, such as the use of ice tongs, steel pins, plates and metal rings are employed, but certainly they are indicated in a relatively small percentage of cases. Satta,<sup>7</sup> of Bologna, however, has used the metal ring, similar to Parham bands, with very favorable results as secondary treatment in correction of deformity. Speed<sup>8</sup> has adopted a method of vertical sus-

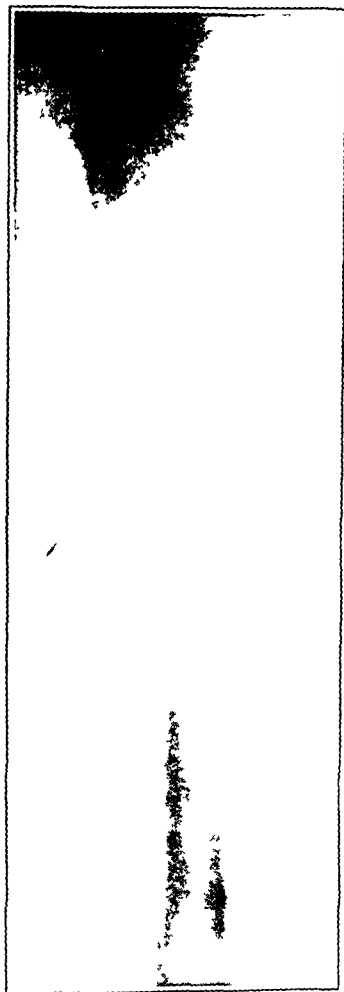


Figure 5

Fig 5—Femur of same patient as in Figure 4, four days after fracture



Figure 6

Fig 6—Oblique fracture of middle third of femur of patient, 2 years of age, roentgenogram taken at time of fracture

pension, obtaining practically the same traction as in the overhead method, but it is more complicated, inasmuch as a Thomas splint is used. I believe that he has been a bit unfair to himself in stating

<sup>7</sup> Satta, F. *Chir d org di movimento* 4 311-345 (July) 1920

<sup>8</sup> Speed, Kellogg. *Surg, Gynec & Obst* 32 527-534 (June) 1921

results in terms of anatomic value, because many of his patients in whose cases the results were marked poor will quite certainly return a few years hence with perfect functional, and probably perfect anatomic, results

Close observation of the progress of healing is made by the portable roentgen-ray machine, while the extremity is in traction. However,



Figure 7

Fig 7—Same patient as in Figure 6, two and one-half years after fracture, overhead traction used

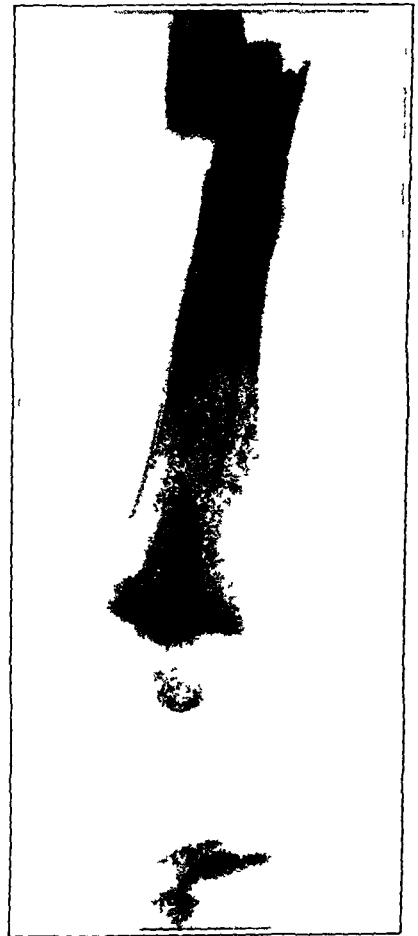


Figure 8

Fig 8—Transverse fracture of middle third of femur of patient 1½ years of age, roentgenogram taken at time of fracture

within a few days the pain of jolting is eliminated and the bed may be moved to the roentgen-ray room as often as desired without disturbance to the child. The simplicity of the treatment affords adequate allowance for this.

## ANALYSIS OF RESULTS

Although the condition of the patient when discharged from the hospital is a fair criterion of the ultimate result, accurate estimation of the physical condition cannot be made until he has been observed for at least one year. Therefore, an attempt has been made to secure the greatest number of returns possible. However, only eleven of the thirty-one patients returned for observation. We hope and rather firmly believe, however, that the reason for failure to get a more complete return lies in the fact that the results have been so satisfactory that the patients deemed an examination unnecessary. Especially is this likely, since the patient with the only unsatisfactory result was practically the first to return after receiving notification. This patient (Fig 17) was an infant, 1 year of age, with a history of greenstick fracture of the middle third of the femur, which occurred twelve days previous to admission.

TABLE 5—RETURN CASES

Method of Treatment and Kind of Fracture	No of Cases
Overhead traction—	
Oblique	4
Transverse	2
Operative reduction—	
Transverse	1
Cast—	
Transverse (very little displacement)	1
Transverse (very little displacement)	1
Splint—	
Transverse (two weeks old fracture when received)	1
Greenstick (twelve days old fracture when received)	1
Total	11

It was treated by splints previous to entry to the hospital, and was treated so here because apparently only a very slight deformity existed. The deformity consisted of an anterior bowing which, it was believed, could be corrected with minor treatment. The error was seen, however, after several days' observation and operative interference was advised. The mother refused to permit operation and the child was discharged under protest. Subsequent observations (Fig 18), two years later, revealed a marked anterior bowing of the femur, a moderate limp and one-half inch (1.7 cm) shortening of the limb.

That operative reduction is not necessary in transverse fractures, with very few exceptions, is shown quite conclusively by Figures 9 to 14. Roentgenograms in each case revealed complete displacement, with about one-half inch overriding even after several days. Observation, fourteen months after discharge of one patient, and three years

after discharge of the other patient, revealed no deformity except a very slight bone thickening. There was no subjective evidence of fracture whatever.

The oblique fractures, all of which were treated by overhead traction, showed no subjective evidence of fracture. Roentgenograms revealed only a very slight bone thickening. In the late pictures of some of the oblique fractures, no bone change at all could be seen.



Figure 9

Fig 9—Same patient as in Figure 8, three weeks after fracture and application of overhead traction.



Figure 10

Fig 10—Lateral view of femur of same patient as in Figures 8 and 9 two years after fracture.

Figure 15 represents a transverse fracture of the upper third which was put up in a cast after attempted reduction. The failure was seen on roentgenographic examination and operative reduction with use of Lane plates was resorted to by Dr. Fisher. Six weeks later there were

removed by him. Roentgenograms, two years later, revealed perfect alinement, with a moderate bone thickening, quite certainly more thickening than seen in any of the other cases. No shortening was found and no subjective symptoms were detected.

Perhaps one of the most striking observations is the absence of shortening seen in cases which healed with fragments distinctly in an



Figure 11

Fig 11—Anteroposterior view of femur of same patient as in Figures 8, 9 and 10, two years after fracture



Figure 12

Fig 12—Transverse fracture of middle third of femur of patient, 2 years of age, roentgenogram taken at time of fracture

overriding position. Moreover, when the patient returns a few years later, the affected extremity shows no shortening. Repeated roentgenograms of the knee joints a few weeks and a few years after treatment reveal no separation of the femur from the tibia due to stretching of the ligaments about the knee joint. The question arises as to the loca-

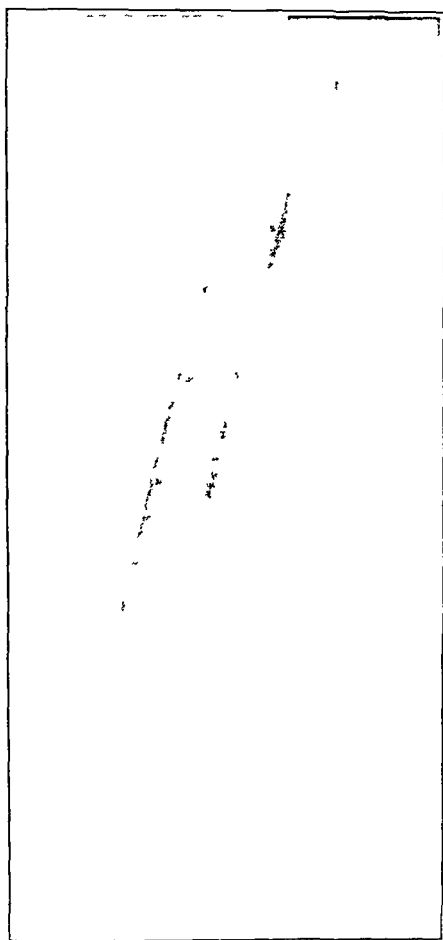


Figure 13

Fig 13—Same patient as in Figure 12 two years after fracture overhead traction used

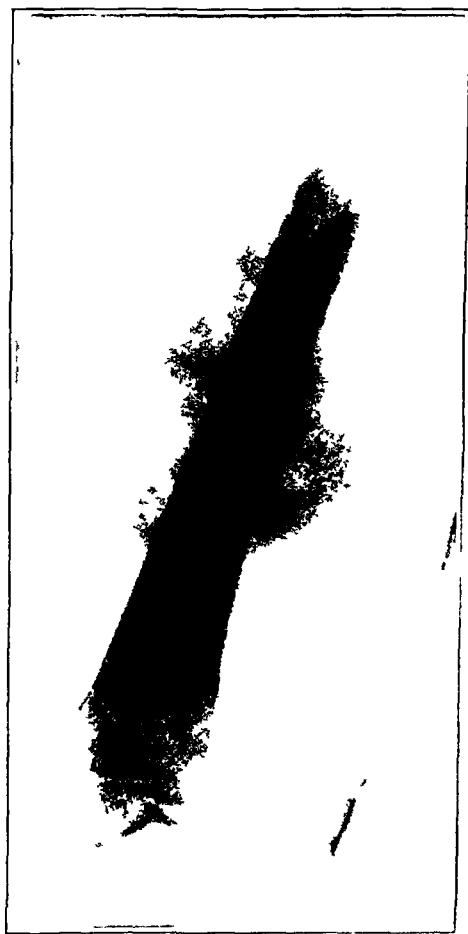


Figure 14

Fig 14—Transverse fracture of upper third of femur of patient 4 years of age roentgenogram taken after attempted reduction and application of cast

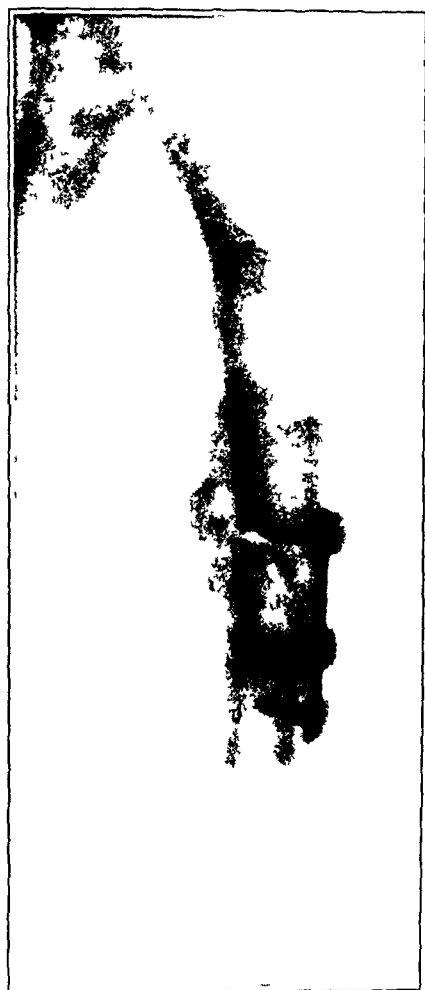


Figure 15



Figure 16

Fig 15—Same patient as in Figure 14, six weeks after application of Lane plate and six and one-half weeks after fracture

Fig 16 — Same patient as in Figures 14 and 15, two years after fracture, showing amount of callus remaining

tion of the compensation. The ligaments of the ankle are not included in the traction at all. Furthermore, one cannot conceive of the hip joint allowing much room for lengthening of the extremity. Apparently, the only explanation remaining is that young bone yields to the constant pull, and thus makes up for the few centimeters necessary for compensation.



Figure 17

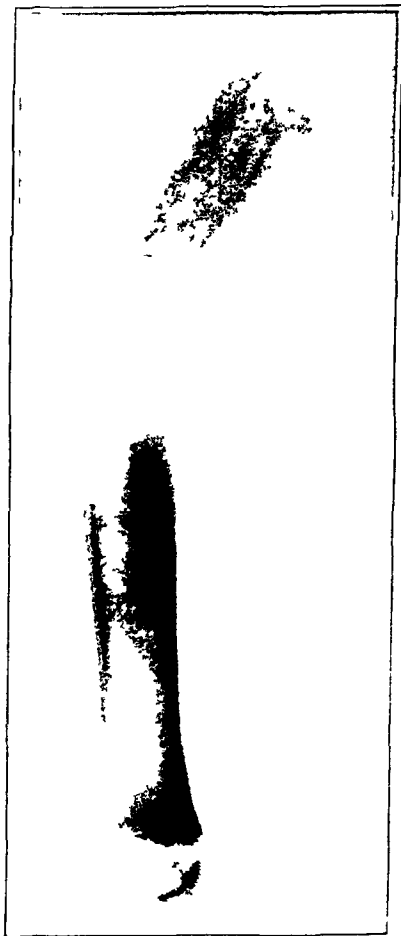


Figure 18

Fig 17—Greenstick fracture of middle third of femur. roentgenogram taken at time of admission. two weeks after fracture. operative reduction was refused and the patient discharged under protest.

Fig 18—Femur of same patient as in Figure 17. two years after fracture. showing marked anterior bowing deformity.



Two occurred in cases of osteomyelitis, one in a case of syphilis, and the last, in a case of osteitis fibrosa cystica.<sup>9</sup> One of the fractures occurring in an acute case of osteomyelitis was an acute case of recent onset, the other was an acute case with a history of chronicity, several months previously. The case of syphilis was complicated by a

TABLE 6—PATHOLOGIC FRACTURES

Cause of Fractures	No of Cases
Osteomyelitis	2
Syphilis	1
Osteitis fibrosa cystica <sup>9</sup>	1

poliomyelitis paralysis in the same extremity as the fracture. The child was given heavy antisyphilitic treatment and discharged wearing a brace.

#### CONCLUSIONS

From the foregoing data, the following conclusions may be deduced:

1. The immediate shortening due to overriding of fragments in growing bone tends to correct itself, even though the fragments have healed in overriding position.

2. Alinement of the fragments is more important than the position of the ends of the fragments.

3. Perfect functional results may be obtained from a transverse fracture, with overriding, by using overhead traction.

4. The younger the patient, the more nature compensates for malposition and surgical inefficiency.

5. Overhead traction is more applicable, and will give better results, than any other method in the treatment of fractured femurs in children.

9. This case is being reported by Dr. Sherwood Moore. Full details will be given in his report.

#### CORRECTION

In the September issue of the ARCHIVES appeared an article on "The Function of the Gallbladder in Biliary Flow" by Conrad Jacobson and Carl Gydesen. A footnote should have accompanied the article to the effect that the experimental work on which the article was based was done in the laboratories of the University of Minnesota Medical School, during the time that Dr. Jacobson served as Associate Professor of Surgery.

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